Biowaste

Decision support tool for collection and treatment of
source-sorted organic municipal solid waste

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Nordic Council of Ministers

Store Strandstræde 18

DK-1255 Copenhagen K

Phone (+45) 3396 0200

Fax (+45) 3396 0202

Nordic Council

Store Strandstræde 18

DK-1255 Copenhagen K

Phone (+45) 3396 0400

Fax (+45) 3311 1870

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Preface

In all the Nordic countries waste management strategies focus on waste minimization and on better utilisation of the resources in the waste.

In all countries better handling of municipal waste is in focus, as it is a significant waste fraction with many unused potentials. In the recent years a number of full-scale systems and projects with source-sorting of the organic fraction of municipal solid waste have been made in order to get a better management. Composting and anaerobic digestion is used for the treatment of the organic waste but to a very different extent in the Nordic countries.

Evaluation of pilot experiments and permanent systems has shown that the economy in the source sorting is very dependent on the collection system (Jørgensen, O. and Jansen, J.I.C, 2003) and that energy production (in case of anaerobic digestion) is significant for the environmental evaluation of the waste handling systems (Jansen J.I. C. and Christensen, T.H, 2003).

A Danish project including four full-scale and large scale experiments has showed that the environmental benefits from household sorting is marginal under Danish conditions if the alternative to sorting and anaerobic digestion of the organic fraction is incineration with co-generation of heat and power. In contrast the benefits from digestion of the organic fraction is significant if the alternative do not include co-generation of energy and heat (Jansen J.I.C. and Christensen, T.H., 2003).

In some international evaluations composting of source-sorted municipal organic waste is pointed out as an economical and environmental friendly handling strategy and internationally composting is one of the most widespread technologies for treatment of the organic fraction of municipal solid waste (Hoog, D, 2002).

Local conditions will always play an important role in systems for handling of municipal waste where collection system and strategy, treatment method and final disposal and utilisation of the products and residues have to be taken into account. Further national conditions and priorities have to be considered too.

A tool for support of local decisions about handling of the municipal organic solid waste should consequently be developed in order to cover the spectrum of technological solutions available today and further include the local conditions and priorities.

The aim of the present project is to develop a computer based decision tool for Nordic municipalities with a wish to evaluate environmental consequences of systems for collection and treatment of the organic fraction of the municipal solid waste.

The tool shall be applicable to Nordic conditions and the data requirement realistic compared to the possibilities of the individual municipalities to get sufficiently safe data without significant costs.

The decision tool is made in collaboration between Swedish and Danish researchers. The group has together and individually made a lot of projects related to collection, treatment and final utilisation of the organic fraction of source-sorted municipal organic solid waste in national projects as well as in Swedish/Danish co-financed projects. Further group members are involved in the development of the elaborated Life Cycle Assessment tools for waste handling that are under constant development in Sweden and Denmark.

The project is financed by the Nordic Council of Ministers and a steering committee is established with members from the Nordic Environmental Protection Agencies. Further a resource team with members from the Nordic Waste organisation is connected to the project.

Steering Committee:

Inge Werther, Danish Environmental Protection Agency
 Cornelis Meyles, Environment and Food Agency of Iceland
 Rita Vigdis Hansen, Norwegian Pollution Control Authority (SFT)
 Erla Olsen, Food-, Veterinary- and Environmental Agency, Faroe Islands
 Elisabeth Møyland, Norwegian Pollution Control Authority (SFT)
 Line Diane Blytt, Norwegian Food Safety Authority
 Catarina Östlund, Swedish Environmental Protection Agency
 Linda Eriksson, Swedish Environmental Protection Agency
 Mervi Leikoski, Finnish Environment Institute

Resource team from Nordic waste organisations:

Christian Rindbøl, Dakofa
 Henning Jørgensen, Reno-Sam
 Hanne Johnsen, affald danmark
 Christoph Gareis, Finnish Solid Waste association
 Henry Nygard, Finnish Solid Waste association
 Henrik Lystad, Norsk renholdsverksforening
 Sigurd Tvedt, Norsk renholdsverksforening
 Gabriella Eliasson, RVF
 Jessica Cedervall, RVF
 Anna Wilhelmsson Göthe, RVF
 Project group:
 Department of Environmental Technology, Lund University:
 Professor Jes la Cour Jansen (project leader)
 PhD-student Åsa Davidsson
 Department of Biometry and Engineering, SLU Uppsala:
 Associate Professor Håkan Jönsson, Institute of Environment and Resources, Technical University of Denmark:
 Professor Thomas Højlund Christensen
 PhD Janus Torsten Kirkeby
 PhD Trine Lund Hansen

1. Overall structure, content and limitations of the model

Overall limitations of the model

A tool for support of decisions at the municipal level has to focus on the most important environmental aspects without losing the national or global perspective. Further the tool needs to be simple in order to secure that the necessary information can be provided locally.

Simplicity is obtained in different ways:

- The frame for the decision is restricted to collection, handling and final utilisation of products and residues from the organic fraction of municipal solid waste. Other types of waste may be handled within the framework but the tool is not intended or prepared for that.
- Only consumptions, emissions and products believed to be significant for local decisions are included. This gives a significant reduction of substances and processes included compared to more sophisticated models. Further it leads to a dramatically reduced need for data collection.
- Data requirement is restricted to the greatest possible extent and the focus is on information available from existing facilities, literature or suppliers. Further basic data collected in projects performed during the recent years are included in the tool and can be selected if appropriate for the actual evaluation.
- Standard data covering needed basic information not related to local conditions is provided.

Overall model structure

The overall model structure is shown in Figure 1.1. Here the physical components of the model are shown. The starting point is the organic waste and the collection system. The pre-treatment is necessary in order to handle any missortings and to remove any plastic bags used in the collection. Further the waste is prepared for further treatment. Two main options exist for handling the waste – composting and anaerobic digestion. Further combined processes where both anaerobic digestion and composting are included seem to appear and are included as well. After the biological treatment products such as compost or gas will be utilised and residues from the treatment have to be incinerated or used for agri-

cultural purposes, production of soil amendment or similar. With the physical structures defined all resources and emissions can be found as indicated in Figure 1.2. Also “negative” emissions (avoided burdens) from substituted activities (electricity production, heat production and production of commercial fertilisers) are included e.g. as any electricity produced replaces electricity from another production. This saving reduces the emission that has to be included in the calculation as a negative emission. From the evaluation of the resources and emissions involved the potential environmental impacts can be found.

Figure 1.1: Physical structures in the model.

Figure 1.2: Physical structures in the model together with the resources and emissions included in the model.

Below details of the model is described. As an introduction the environmental impacts to be quantified are presented. Next the different physical structures from Figure 1 are described in order to make the reader familiar with the technologies and systems and give the necessary background for utilisation of the decision tool.

2. Environmental impacts to be quantified by the model

General description

The tool for evaluation of environmental impacts of source-sorted municipal organic solid waste management uses a simplified method for life cycle assessment. The Danish EDIP (Environmental design of industrial products) method (Wenzel H. et al, 1997) has been used as the base for the environmental assessment calculations. The environmental assessment tool includes a limited number of environmental exchanges (resources and emissions), but the chosen emissions are previously shown to be the most important when evaluating solid waste management systems. The environmental impacts evaluated by this tool are similar to impacts found important in previous Swedish studies (Sundqvist C. et al., 2002a; 2002b) and evaluated by Baký, A. and Eriksson, O. (2003) for the Danish EPA:

- Global warming potential
- Acidification
- Nutrient enrichment
- Photo chemical ozone formation

Human and eco toxicities are omitted from the tool due to very large uncertainties in the toxicity potentials and because the data requirements would increase significantly. Stratospheric ozone depletion is omitted because previous studies have showed that this impact is very insignificant compared to the chosen environmental impact categories above (Kirkeby, J.T. and Christensen, T.H., 2004).

Resources are quantified for energy resources since these are usually the most significant resources when assessing solid waste systems for organic municipal waste. The energy resources are calculated into primary energy (MJ), which describes the energy content of the consumed/replaced energy resources. In addition, the fertiliser components N, P and K are included in the resource quantification.

Characterisation

Results from the environmental assessment tool are given as consumption of energy resources, emissions, potential environmental impacts and primary energy consumption. Finally the normalised potential impacts, where impacts are set on a common reference as the environmental load from an average person is given.

The results are given at the following levels:

- Emissions and energy resources (amount of each substance)
- Potential impacts and primary energy (amount of equivalents and MJ)
- Normalised potential environmental impacts (person equivalents (PE))

Table 2.1 shows how each emitted substance contributes to each of the environmental impact categories.

Table 2.1: Characterization factors for emissions and impacts included in the tool (Wenzel H. et al, 1997)

Characterisation factors	Global warming (100 years)	Acidification	Nutrient enrichment	Photo chemical ozone formation
	CO ₂ -equivalents	SO ₂ -equivalents	NO ₃ ⁻ equivalents	C ₂ H ₄ -equivalents
CO ₂	1			
CO	2			
CH ₄	25			0.007
N ₂ O	320			
NO _x		0.7	1.35	
NH ₃		1.88	3.65	
NO ₃ ⁻ -N			4.44	
P-tot			32	
SO ₂		1		
NMVOC, diesel engines				0.5
HCl		0.88		

Resource consumptions are calculated for the following parameters:

- Recycling amount of fertiliser components N, P and K
- Each energy resource (natural gas, coal, lignite, oil and biogas)
- Primary energy (common reference for all energy resources)

Some waste treatment strategies of source-sorted municipal organic solid waste may lead to recycling and utilisation of nutrients in agriculture and possible commercial fertiliser is displaced. The environmental assessment tool will calculate the amounts of fertiliser components nitrogen, phosphor and potassium in the reused organic waste. Also the production and the necessary energy for production of alternative commercial fertiliser are included in the calculations as avoided processes.

Energy resources consumed and displaced from energy and fertiliser production are calculated for each energy resource and as a sum of pri-

primary energy carrier. Primary energy defines the energy content in the energy resources and by this calculation the energy resources are calculated on a common reference. Table 2.2 shows the energy content in resources used for primary energy consumption/savings.

Table 2.2: Primary energy in energy resources (Energistatistik, 2004)

	Primary energy	Unit
Hard coal	26.5	GJ/ton
Crude oil	43.0	GJ/ton
Lignite	18.3	GJ/ton
Natural gas	39.9	GJ/1000 Nm ³ CH ₄
Biogas	36.0	GJ/1000 Nm ³ CH ₄

Normalisation

Normalisation factors for environmental impacts represent the environmental load of an impact from an average person, due to his/her activities in society (transport, heating, electricity, material goods etc.). Normalisation enables comparison between the environmental impact categories and simplifies the evaluation of the overall results. There are normalisation factors for each environmental impact category of which some are global (global warming) impacts and others are more local or regional (nutrient enrichment, acidification and photochemical ozone formation). The normalisation factor should represent the load of an average person in the region thus; normalisation factors may be different for regional and local impacts categories. The normalisation factors currently existing in the EDIP method is for global, EU-15 countries and Denmark see Table 2.3.

Table 2.3: Normalisation factors

Normalisation references	Global warming	Acidification	Nutrient enrichment	Photo chemical ozone formation
	kg CO ₂ -eq/pers/yr	kg SO ₂ -eq/pers/yr	kg NO ₃ ⁻ -eq/pers/yr	kg C ₂ H ₄ -eq/pers/yr
Global ^a	8700	59	95	22
EU-15 ^a	8700	74	119	25
Denmark	8700	101	260	20
Finland	-	-	-	-
Iceland	-	-	-	-
Norway	-	-	-	-
Sweden	7670 ^b	40 ^c	d	e

- (Wenzel H. et al, 1997)
- (Tidåker, P., Kärrman, E., Baky, A. and Jönsson, H. 2005).
- Excluding emissions of HCl (Tidåker, P., Kärrman, E., Baky, A. and Jönsson, H. 2005).
- Emissions of NH₃ was 6.2 kg/person, year and of NO_x 27 kg/year (Tidåker, P., Kärrman, E., Baky, A. and Jönsson, H. 2005)

- e. Emissions of methane in Sweden were 30,47 kg/person, year and of NMVOC 28,35 kg/person, year (National Green House Inventory for 2004, (2004)) and for the population (SCB, 2006)

3. Waste input

General description

The starting point for evaluation of the waste handling is to define the waste input. Since the tool is intended for assessment of source-sorted organic household waste, only the amount of input waste (ton) as well as the chemical composition for this type of waste is needed.

Waste characterisation

The chemical waste composition is described by the content of total solids (TS), water content, volatile solids (VS), calorific value (MJ/kg TS), methane potential (STPm³ CH₄/t VS) and C, N, P, K. Further the content of plastic (% of TS) is needed.

The composition of the collected waste is affected by the collection system, especially choice of collection bags and the sorting instructions. Table 3.1 describes five examples of Danish collection systems investigated by the Danish EPA 2001-2002 (Hansen T.L. et al, 2007a). These systems can be used for selection of waste composition if no other information is available.

The sorting system must fit the chosen system for further treatment (pre- or post-treatment as well as anaerobic digestion or composting). Especially use of plastic bags for collection requires extensive pre- or post-treatment to obtain a high quality end product.

Table 3.1: Description of five Danish collection systems (Hansen T.L. et al, 2007a)

	System 1 (Copenhagen)	System 4 (Kolding)	System 3 (Vejle)	System 2 (Aalborg)	System 5 (Grindsted)
Collection system	Experimental	Experimental	Permanent	Experimental	Permanent
No of households, total	16366	2037	26339	2294	7250
Single family	2433	1623	12643	647	6050
Multi family	13933	414	13696	1647	1200
Bag type, in door	Paper	Plastic	Plastic	Plastic	Paper
Bag type, out door	Paper/container	Paper	Container	Container	Paper
Sorting instructions					
Food leftovers (raw or cooked)	x	x	x	x	x
Fruit and vegetables	x	x	x	x	x
Meat (without bones)	x	x	x	x	x
Animal bones		-	x	x	
Coffee and tea (incl. filters)	x	x	x	x	x
Kitchen paper/napkins (used)	x	x	x	x	x
Animal fodder				x	
Animal excrements	x		x		
Cat litter		x	x		
Flowers, cut		x	x	x	x
Flowers (incl. soil)		x	x	x	
Diapers		-	x		

Table 3.2 shows the chemical composition and methane potential (average) of the organic waste collected in the five systems (Hansen T.L. et al, 2007b).

Table 3.2: Composition of the collected waste (averages of dry matter), different systems and overall averages (Hansen T.L. et al, 2007b)

	System 1 (Copenhagen)	System 4 (Kolding)	System 3 (Vejle)	System 2 (Aalborg)	System 5 (Grindsted)	Average
Number of samples	12	8	8	7	5	
TS [% of ww]	29	30	30	25	32	29
Water [% of ww]	71	70	70	75	68	71
VS [% dm]	91.6	86.1	87.0	86.7	89.5	88.2
Calorific value [MJ/kg dm]	20.8	19.7	19.7	20.1	20.3	20.1
Methane potential [STPm ³ CH ₄ /t VS]	428	469	471	488	438	459
C [% dm]	49.2	47.2	47.3	48.1	48.1	48.0
N [% dm]	2.5	2.5	2.4	2.6	2.4	2.5
P [% dm]	0.4	0.4	0.4	0.4	0.3	0.4
K [% dm]	1.0	0.9	0.8	0.9	0.9	0.9
Plastic [% dm]	1.9	7.2	8.1	6.9	-	6.0

The contents of plastic and ash were found to vary between the investigated collected systems. The choice of collection bag material (plastic or paper) was determining the amount of plastic in the collected waste, while the ash content was influenced by the sorting instructions, especially inclusion of soil (together with flowers) and cat soil. Although the differences in waste composition between collection systems were significant for several chemical parameters, the differences were relatively small in the context of influencing the results of further treatment.

4. Waste collection

General description

Fuel consumption for waste collection is divided into two parts: the actual collection of waste at each source in an area and the transportation of a full load of waste from the collection area to initial treatment. The waste collection is defined as fuel consumption per ton of waste (MJ/ton) and default values can be given for different types of residential areas and for different type of collection. The values vary much from area to area due to distances and population density, waste collection equipment, waste collection vehicle type and size etc. Thus it may be important that each involved country collects reasonable and well-documented data for fuel consumption for waste collection.

Energy use

Table 4.1 shows the fuel consumption for different types of residential areas. The user of the tool should choose among these types. Local data is preferred but the values in the table are suggested if no local data or local estimates are available.

Table 4.1: Typical fuel consumptions for waste collection in different types of residential areas (after Kirkeby J.T. and Christensen T.H., 2004)

	Traditional collection	Separate collection	Unit
Single family housing	118	236	MJ/ton
Multi family housing	118	236	MJ/ton
City areas	118	236	MJ/ton
Sub urban areas	250	500	MJ/ton
Mixed residential areas	144	288	MJ/ton

Transport of waste from collection area to initial treatment is defined by the distance from collection area to initial treatment (km) and fuel consumption per transported ton of waste (MJ/ton/km). This consumption depends on type and size of waste collection vehicle. Table 4.2 shows the necessary input for defining the fuel consumption for transportation of the collected waste. The overall fuel consumption is calculated by adding fuel consumption for collection and transport.

Table 4.2: Necessary input for defining fuel consumption for waste transportation

Transportation between collection area and initial treatment facility		
Distance to pre-treatment plant	xx	km
Distance to incineration plant	xx	km
Distance to landfill	xx	km
Specific fuel consumption for transport	xx	MJ/ton/km

The fuel type for both collection and transport is chosen to be either diesel or methane. The choice influence the emissions from fuel combustion and thereby the overall potential environmental impacts.

5. Pre-treatment

General description

The purpose of the pre-treatment stage is to separate missortings, any plastic bags used in collection or other items that can disturb the process or the quality of the residues from the organic material before anaerobic digestion or composting. Some post-treatment after biological treatment may also increase the quality of the residues. The pre-treatment stage comprise of a number of different processes such as:

- a. Reception (weighbridge, tipping place, bunker)
- b. Pre-treatment
- c. Grinders/shredders for bag opening and size reduction of the material prior to separation.
- d. Separators for separation of metals, plastics, stone and gravel etc.
- e. Hygienisation (optional)
- f. Any treatment of residues from pre-treatment

The tool focuses on the overall separation of the waste into biomass for biological treatment and reject for incineration, as the reject will not be accepted for landfilling. In each case the mass of the collected waste has to be distributed between these two fractions. This holds for the total and volatile solids, the water and all the constituents and components of the waste as described in chapter 4. Since different separations techniques have shown to distribute the fractions different it is necessary to base the distribution on the selected pre-treatment technique.

For some common pre-treatment technologies examined in a Danish/Swedish co-project allocation parameters exists for distribution between biowaste and reject as shown in Table 5.1. These values or the build in default values can be used if no local information is available.

Table 5.1: Distribution of the waste components between biowaste and reject from some Danish pre-treatment systems (Hansen T.L., 2006b). The table gives the fraction that ends up in the biowaste

Pre-treatment system	Disc screen (Copenhagen)	Hydraulic screw press (Aalborg)	No- pre-treatment (Grindsted)
Water	0.73	0.66	1
Ash	0.634	0.549	1
VS	0.624	0.531	1
C	0.634	0.545	1
N	0.667	0.561	1
P	0.677	0.662	1
K	0.647	0.575	1
Plastic	0.05	0.05	1

Energy use

The pre-treatment may require consumption of electricity, heat or oil, which should be defined by the user. All consumptions related to the pre-treatment should be included. If hygienisation of the waste takes place as part of the pre-treatment the energy consumptions should be included as well. Table 5.2 gives the consumptions needed from the user together with suggestions from the different systems in Table 5.1.

Table 5.2: Data requirement for consumptions (Christensen T.H. et al., 2003)

Pre-treatment system	Disc screen (Copenhagen)	Hydraulic screw press (Aalborg)	Minor* pre-treatment (Grindsted)
Power consumption kWh/ton	20	11	~0
Oil consumption l/ton	0	0	0

* Only shredder and magnetic separation is used.

Emissions

No direct emissions for the impact assessment are assumed to take place during pre-treatment. Indirect emissions related to the use of energy will be included.

6. Composting

General description

The composting module describes the biological degradation of organic matter, air emissions from the process and the amount and composition of the resulting output fractions. Different composting technologies can be modelled. High technology plants will typically use more energy, and have more controlled air emissions (higher removal ratios) than low technology plants.

Degradation and distribution of the organic waste in composting

The organic matter is degraded according to a user defined degradation ratio for volatile solids (VS). Local data should be used if available otherwise the degradation ratios in Table 6.1 can be used.

Table 6.1: Degradation ratio (VS) for different composting technologies (estimate based on Starberg K., 2005)

Unit		Compost technology 1: Windrow composting	Compost technology 2: Reactor composting	Compost technology 3: Home composting
Degradation ratio	% of VS	44	44	44

After degradation the remaining dry matter is distributed between one to four output fractions: Composted organic waste as well as different residue fractions. Most components will follow the dry matter, but e.g. plastic will often behave different. The distribution of all components included in the tool can be defined by the user, see Table 6.2. Since the water content of the output fractions is more depending on the process (drying and watering of the material during the composting process) than the input water, the dry matter content of each output fraction is user defined. Often the composted organic waste is separated into several output fractions. In the table the user can define up to 3 different residues. The number and types depend on the quality of the waste and the utilisation of the compost product.

Table 6.2: Distribution of dry matter after degradation must be defined for each composting technology together with the dry matter content in each output fraction (example)

	Compost	Residue 1	Residue 2	Residue 3
Weight kg/t waste				
TS% of ww	75	20	5	0
VS % of TS	75	20	5	0
C % of TS	75	20	5	0
N % of TS	75	20	5	0
P % of TS	75	20	5	0
K % of TS	75	20	5	0
Plastic % of TS	5	85	10	0
Dry matter content in output fractions	55	70	60	0

Consumptions

The composting plant has a certain consumption of electricity and heat, which should be defined by the user. Proposals are given in Table 6.3 if no local data exist. Other consumptions may also be included.

Table 6.3: Consumption and general factors for three different composting technologies (examples)

	Unit	Compost technology 1: Windrow composting	Compost technology 2: Reactor composting	Compost technology 3: Home composting
Fuel consumption	l/ton	3.6*	2	0
Electricity consumption	kWh/ton	0	5	0

*From Herning kommune Miljøafdelingen (2004)

Emissions

During the composting process the nitrogen in the organic waste may be lost. The total nitrogen emissions to air from the composting process are quantified as % nitrogen lost (% of the total nitrogen in the ingoing waste). These emissions depend strongly on the composting technology and specific conditions, e.g. aeration, dry matter content, C:N ratio and temperature. Presently the nitrogen emissions are estimated at 17%, irrespective of the compost technology.

This estimation of 20% is half of that arrived at by use of Kirchmann's equation on the default waste. The nitrogen emissions when composting at 60-70°C seems to be estimated by this equation:

$$E_N (\%) = 55.903 - 1.108 \cdot C/N \quad (\text{Kirchmann H., 1985})$$

where

C/N = the C:N ratio in the composting material (including structure material, if this is added)

If the composting mainly is performed in the range of 50-60°C, instead of 60-70°C the nitrogen loss seems to be only half of Kirchmann's estimation (Eklind Y., et al., 2005). The estimated N loss of 17% in Table 6.4 was arrived at by assuming a C/N ratio of the compost substrate, including structure material, of 20, using Kirchmann's equation and then dividing by two as, the compost temperature was assumed to be 50-60°C. If the C/N ratio of the compost substrate, including structure material, is significantly different than 20, then the nitrogen loss ought to be recalculated.

Table 6.4: Air emissions from different composting technologies (estimates)

	Unit	Compost technology 1: Windrow composting	Compost technology 2: Reactor composting	Compost technology 3: Home composting
N loss	% of N total	17	17	17
Methane production	% of CO ₂ -C emission	1	1	1
NM VOC production	% of CO ₂ -C emission	2	2	2

Amlinger F. and Peyr S. (2003) reports lower losses (0.4-9%), but in their measurements, the composts did not reach full stability and they thus only measured part of the total nitrogen loss to reach a stable compost. This might also be why they found the relative proportion of the N₂O emission to be 7-17%, much higher than the value found in Table 6.5, which gives the distribution of the nitrogen emission between NH₃, N₂O and N₂.

Table 6.5: Distribution of the total nitrogen loss between the different nitrogen species (Sonesson U., 1996)

Distribution of N loss	NH ₃	N ₂ O	N ₂	Sum
% of total N loss	96	2	2	100

Methane formation may occur in anaerobic parts of the material. Also non-methane volatile organic carbons (NMVOCs) can be produced in the compost. No general applicable data can be given and new research may change the estimates (best guesses) given in Table 6.4. The formation of these substances is quantified as a percentage of the CO₂ produced through degradation of the organic matter. Amlinger F. and Peyr S. (2003) measured the relative proportion of the emitted C as methane to be 0.1-0.9% for garden waste and 0.6-1.8% for biowaste in windrows and 1.6-2.8% for large (800 litres) home composts. It is by default set to 1% for the different compost technologies (Table 6.4).

Gas cleaning (biofilter or similar technology) can be added to the plant in terms of separate removal rates for methane, ammonia and nitrous oxide as shown in Table 6.6, but literature values vary a lot. Reduction of methane in the gas cleaning step result in CO₂ production, while it is assumed that degradation of ammonia yields N₂.

Table 6.6: Removal efficiency for the gas cleaning (Pitschke T. et al., 2004)

		NH ₃	N ₂ O	CH ₄
Gas cleaning	% removal	95	0	50

The user must define the chemical form of the nitrogen in the output compost, see Table 7.7 for the default. This influences the behaviour of nitrogen when applied to the agricultural soil.

Table 6.7: Distribution of nitrogen between the different species in the output compost (estimates)

		NH ₃	NO ₃ ⁻	Org. N	Sum
N distribution in output	%	1	6	93	100

Structure material

Organic household waste will often be mixed with e.g. yard and garden waste to create a better composting process by improving the structure and lowering the C:N ratio. This structure material is not included in the model, since it is assumed that the material is not specifically produced for the composting process, but will often be another waste fraction, such as garden waste. The main treatment technology for garden waste is composting (alone or mixed with other waste types).

When defining the C:N ratio for calculation of the total nitrogen loss, however, the structure material should be included. Otherwise the nitrogen loss will be too high (corresponding to the assumption that household waste has been composted alone).

Measurements on the output streams (weight and dry matter content) should also be corrected by the user for the input of structure material.

7. Anaerobic digestion

General description

The module for anaerobic digestion describes degradation of organic matter and separation of the waste in gas and in different residual fractions. All kind of anaerobic digestion can be modelled.

Degradation and distribution of the organic waste in anaerobic digestion

The organic matter is separated in three different fractions before anaerobic digestion. Sediment and floating material that appear in the process is diverted from the biomass and incinerated or dumped on a landfill. The biowaste is degraded according to a user-defined degradation ratio based on the content of volatile solids (VS). The remaining solids may be separated after the digestion in a fibre fraction and a liquid fraction. From the degraded volatile solids the gas production is found. The fibre fraction can be used on land or incinerated. The liquid fraction is used on land as fertiliser. If no local data or assumptions are available the degradation ratios in Table 7.1 can be used.

Table 7.1 gives the needed distribution of the biomass in sediment, floating material and degraded volatile solids within anaerobic digestion and in the fibre- and liquid fraction in the post-separation.

Table 7.1: Distribution of the biowaste into sediment, floating material and degraded volatile solids, together with the division of the digester residue in fibre- and liquid fraction (examples from Christensen T.H. et al. (2003))

	Grindsted mesophilic	Herning thermophilic	Vaarst-Fjellerad thermophilic
Sediment %	0.75	0.5	1
Floating material %	1	0.5	0.5
Degraded volatile solids %	75	75	75
Part to fibre fraction %	35	0	0
Total solids content in fibre fraction % TS	50	0	0

Energy use

The main consumptions are electricity for operation and heat for keeping the temperature in the digester. Further consumptions associated with the digestion are assumed to be negligible. Table 7.2 gives suggestions based

on results from different plants. These can be used or local data can be selected if available.

Table 7.2: Consumption related to anaerobic digestion and post treatment of residues (examples)

	Grindsted me- sophilic	Herning ther- mophilic	Vaarst-Fjellerad thermophilic
Power consumption kWh/ton	25	25	20
Heat consumption GJ/ton	0.12	0.22	0.22
Heating of biomass °C	37	55	55

Gas production and utilisation

Anaerobic digestion leads to methane production and the specific methane production needs to be given or selected together with the methane content. Further the utilisation of the biogas has to be given. Table 7.3 summarises the needed information.

Table 7.3: Biogas production, methane content and gas utilisation (example)

	Distribution of the utilisation
Produced methane Nm ³ CH ₄ /ton VS input	450
Methane content in biogas Volume %	65
Utilisation	
Transportation fuel %	30
Heat production %	0
Power production %	70
Gas for the grid %	0

Emissions from upgrading and utilisation of biogas

Utilisation and upgrading of biogas leads to consumptions and emissions. Table 7.4 summarises the needed information.

Table 7.4: Resource use and emissions from upgrading and utilising biogas

Gas utilisation technology	Unit	Grindsted electricity	Herning combined heat and power	Vaerst-Fjellerad combined heat and power	Upgrade and use in busses
Electricity consumption of upgrading	kWh/MJ upgraded gas	0	0	0	0.057
Total energy recovery rate	%	40	85	85	0
Power recovery rate	%	40	38	38	0
Heat recovery rate	%	0	47	47	0
Emission of methane	% of methane	3	3	3	3
Methane percentage in biogas	%	65	65	65	65
Air Emissions					
CO ₂	g/MJ com- busted gas				0
NO _x	g/MJ com- busted gas				0.233
HCl	g/MJ com- busted gas				
CO	g/MJ com- busted gas				0.0241

8. Combined digestion and composting

General description

Some biological treatment plants combine anaerobic digestion with composting, either in the same reactor or as a combination of anaerobic digestion followed by e.g. windrow composting. This module is a combination of the composting module and the biological treatment module. Different technologies combining anaerobic digestion and composting can be modelled. Energy consumption, degradation ratio and control of air emissions depend on the technology level and the physical features of the plant.

No data has been available for combined treatment so the user has to provide data for the different processes. Data in the tables is examples for illustration only.

Degradation and distribution of the organic waste in composting

Plants combining anaerobic digestion and composting need to include degradation and distribution of the organic waste from both processes. If no local data or assumptions are available the data in Table 8.1 should be used with caution.

Table 8.1: Degradation ratios for anaerobic digestion and composting in a technology combining these two biological treatment methods. Data for illustration only

		Anaerobic digestion	Composting
Degradation ratio	% of VS	65	15

The remaining dry matter will be distributed between one to four output fractions: Treated waste as well as residue fractions. Most components can be assumed to follow the dry matter, but it may be different for e.g. plastic, nitrogen and potassium. The distribution of all components included in the tool can be defined by the user, see Table 8.2. Since the water content of the output fractions is more depending on the process (drying and watering of the material during the combined process) than the input water, the dry matter content of each output fraction is user defined.

Table 8.2: Distribution of dry matter after degradation must be defined for each combined technology together with the dry matter content in each output fraction (example)

	Treated waste	Residue 1 (floating material)	Residue 2 (fluent)	Residue 3
Dry matter distribution%	75	20	5	0
VS%	75	20	5	0
C%	75	20	5	0
N%	5	20	75	0
P%	75	20	5	0
K%	5	20	75	0
Plastic%	5	90	5	0
Dry matter content in output fraction	55	70	5	0

Energy use

The combined plant has a certain consumption of electricity and heat, which should be defined by the user. Other consumptions may also be included. Table 8.3 gives an example.

Table 8.3: Consumption and general factors for two different composting technologies (examples)

	Unit	Aikan Combined technology:	Other Combined technology 1*:
Fuel consumption	l/ton	6.6	2
Electricity consumption	kWh/ton	6	5

*(From Herning kommune Miljøafdelingen, 2004)

Emissions

During anaerobic digestion no emissions are assumed to occur, since the process is contained in a closed reactor (see Chapter 7).

During the composting process the nitrogen in the organic waste may be lost. Very little is known about emissions from compost from a combined process and at present the same assumption as for normal composting is applied in the model.

The total nitrogen emissions to air from the composting process are quantified as % nitrogen lost (% of the total nitrogen in the ingoing waste). These emissions depend strongly on the composting technology and specific conditions, e.g. aeration, dry matter content, C:N ratio and temperature. Presently the nitrogen emissions are estimated at 17%, irrespective of the compost technology.

This estimation of 17% is half of that arrived at by use of Kirchmann's equation on the default waste. The nitrogen emissions when composting at 60-70°C seems to be estimated by this equation:

$$E_N (\%) = 55.903 - 1.108 \cdot C/N \quad (\text{Kirchmann H., 1985})$$

where

C/N = the C:N ratio in the composting material (including structure material, if this is added)

If the composting mainly is performed in the range of 50-60°C, instead of 60-70°C the nitrogen loss seems to be only half of Kirchmann's estimation (Eklind Y. et al., 2005). The estimated N loss of 17% in Table 8.4 was arrived at by assuming a C/N ratio of the compost substrate, including structure material, of 20, using Kirchmann's equation and then dividing by two as, the compost temperature was assumed to be 50-60°C. If the C/N ratio of the compost substrate, including structure material, is significantly different than 20, then the nitrogen loss ought to be recalculated.

Table 8.4: Air emissions from different composting technologies (estimates)

	Unit	Aikan Combined technology:	Other Combined technology 1:
N loss	% of N total	17	17
Methane production	% of CO ₂ -C emission	1	1
NMVOG production	% of CO ₂ -C emission	2	2

Amlinger F. and Peyr S. (2003) reports lower losses (0.4-9%), but in their measurements, the composts did not reach full stability and they thus only measured part of the total nitrogen loss to reach a stable compost. This might also be why they found the relative proportion of the N₂O emission to be 7-17%, much higher than the value found in Table 8.5, which gives the distribution of the nitrogen emission between NH₃, N₂O and N₂.

Table 8.5: Distribution of the total nitrogen loss between the different nitrogen species (Sonesson U., 1996)

Distribution of N loss	NH ₃	N ₂ O	N ₂	Sum
% of total N loss	96	2	2	100

Methane formation may occur in anaerobic parts of the material. Also non-methane volatile organic carbons (NMVOCs) can be produced in the compost. No general applicable data can be given and new research may change the estimates (best guesses) given in Table 8.4. The formation of these substances is quantified as a percentage of the CO₂ produced through degradation of the organic matter. Amlinger F. and Peyr S. (2003) measured the relative proportion of the emitted C as methane to be 0.1-0.9% for garden waste and 0.6-1.8% for biowaste in windrows and 1.6-2.8% for large (800 litres) home composts. It is by default set to 1% for the different compost technologies (Table 8.4).

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When defining the C:N ratio for calculation of the total nitrogen loss, however, the structure material should be included. Otherwise the nitrogen loss will be too high (corresponding to the assumption that household waste has been composted alone).

Measurements on the output streams (weight and dry matter content) should also be corrected by the user for the input of structure material.

9. Use on land

General description

Nutrients and organic matter are valuable in agriculture and treated organic waste may therefore be applied to agricultural land possibly substituting commercial fertilisers. Apart from the direct substitution effects (saved energy and emissions from production of commercial fertilisers) the application will affect the environmental impacts from the fields after spreading. The nutrients in treated organic waste behave differently than nutrients in commercial fertilisers mainly due to different chemical forms. This affects the nutrient losses from the system, e.g. leakage, surface run-off and emissions to air.

Consumptions and substitution

The main consumptions in this module will be diesel for the actual spreading of the treated organic waste. This consumption will be defined as MJ/ton waste, see Table 9.1.

Table 9.1: Diesel consumption is the main resource consumption from the use on land module (estimate)

Unit		
Diesel consumption	MJ/ton	0.3

The treated organic waste is assumed to substitute commercial fertilisers. The extent to which the commercial fertilisers are actually replaced by the treated organic waste are defined by the utilisation ratios defining the part of nitrogen, phosphorus and potassium in the waste replacing commercial nitrogen, phosphorus or potassium fertiliser. The magnitude of this ratio is depending on the chemical form of the nutrients in the treated organic waste, the local conditions at the agricultural field, agricultural practice and legal regulations. If no local data are available, the data in Table 9.2 can be used.

Table 9.2: Utilisation rates for the treated organic waste determining the fraction of the organic nutrients substituting commercial fertilisers (example)

	Unit	N organic	N mineral	P	K
Utilisation ratio	% utilized compared to commercial fertilisers	30	80	100	100

Emissions

The module includes emissions of nitrous oxide and ammonia to air as well as nitrate to water. The emissions are quantified by emission coefficients describing the percentage of applied nitrogen emitted as the substance to the environment. The emission coefficients must be defined based on the comparison of two scenarios: A standard scenario, where only commercial fertiliser is applied and a scenario where treated organic waste is substituting commercial fertilisers. The emission coefficient is defined as the difference in emitted substance (kg) divided by the amount of nitrogen applied with the treated organic waste. These coefficients are highly site- and case-specific, since they depend strongly on factors such as soil-type, climate and agricultural practice. The emission coefficients for this module may be derived through models for simulation of soil processes in agriculture, field experiments or literature.

Emissions of phosphorus to surface and ground water are not included in the module. These emissions are strongly depending on the history of the soil concerning phosphorus fertilization, the mechanisms are not well known and the emissions can therefore not be directly related to the phosphorus in the applied fertilisers. Heavy metal emissions to the soil from the applied treated organic waste are not included, since they will contribute only to toxicity effects, which are not included in this tool.

Carbon dioxide from degradation of organic matter is usually considered “neutral” with respect to global warming, since the degraded plants have recently removed a similar amount of carbon from the atmosphere during growth. However, when applied to agricultural soil some organic matter may be temporary or permanently bound in the soil thereby making a delay or saving in carbon dioxide emissions. This effect is called carbon sequestration and the magnitude of the effect is depending very much on assumptions about agricultural practice and the time limits for the modelling. In the module, carbon sequestration is defined as a percentage of the applied carbon assumed to be permanently incorporated in the soil.

No general default values can be recommended due to the dependency of local conditions. The ranges shown in Table 9.3 represent different Danish conditions simulated in the agroecosystem model Daisy (Bruun S. et al, 2006).

Table 9.3: Coefficients for land application of treated organic waste. The data in the table are the result of comprehensive simulations of Danish conditions in the agro-ecosystem model Daisy described further in Bruun S. et al (2006)

	Unit	
Ammonia to air	N/N applied	0.016 - 0.11
Nitrous oxide to air	N/N applied	0.013-0.022
Nitrate run off to surface water	N/N applied	0-0.27
Carbon permanently bound in the soil	C/C applied	X

The ammonia emissions to air mostly depend on the spreading technique and the speciation of nitrogen in the treated organic waste. High ammonia content increases the risk of ammonia loss. The nitrous oxide emissions depend on several factors and no simple correlation can be given. Nitrate run-off to surface waters through drains or direct run-off depends mainly on the topography and soil type (larger run-off from hilly clayey fields than flat sandy fields). The amount of carbon remaining in the soil changes over time. Daisy simulations showed that after 10 years in average 80% of the spreaded carbon remained in the soil, after 50 years 30% was left and after 100 years around 10% was left. The actual effect of carbon sequestration depends on the time frame used.

10. Incineration

General description

Waste incineration has several purposes. First, the aim is to reduce the volume of waste; secondly, energy can be recovered as electricity and/or district heating. However, waste is neither a clean nor homogeneous fuel and advanced flue gas cleaning is necessary to meet regulations on emissions.

Consumptions

The incineration needs material and energy to be able to function properly. In this respect the energy demand is the most essential consumption to quantify, thus electricity, heat, natural gas and oil must be quantified per ton of waste combusted. Secondly, the energy efficiencies for production of electricity and/or district heating must be quantified as percentages of the lower heating value of the waste. The lower heating value is based on the volatile solid (VS) content combined with the specific lower heating value (MJ/ton VS) in the waste. Consumption of other materials such as lime, acids and chemicals are omitted because they usually are used in small amounts or because they are assumed to be a less environmental burden during production. Also, the energy balance has shown to be the most significant environmental issue from incineration plants compared to material consumption (Kirkeby, J.T. and Christensen, T.H., 2004).

Emissions

Emissions arising from the incineration facility is defined to be process specific, thus, depends on the amount of waste to be combusted and not on the chemical composition of waste. Process specific emissions to be quantified are: CO, CH₄, SO₂, HCl, NO_x, NH₃, N₂O, and NMVOC. Carbon dioxide emissions from incineration of organic household waste are assumed to be CO₂-neutral, thus, not contributing to global warming.

Any produced wastewater will be led to a wastewater treatment plant resulting in electricity consumption. Emissions from wastewater treatment are omitted from the overall results. Since the major environmental impacts due to waste incineration are due to air emissions these emissions are in focus in this tool. All necessary input to incineration technologies are seen in Table 10.1.

Incineration residues (bottom ash and air pollution control (APC) residues) are not included in calculation in this model, since any emission occurring from disposal of these only affect the chosen environmental impacts categories to a minor extent.

The structure of the incineration model enables calculation of most types of incineration technologies with different types of oven, flue gas cleaning etc. since all input and output are defined as process specific. The user should add own local data or choose one of defined incineration technologies in the environmental assessment tool.

Table 10.1: Input table for incineration technologies (unpublished data from Danish power plants)

INCINERATION PLANT	Unit	Incineration plant, Technology 1	Incineration plant, Technology 2
Input			
Power consumption	kWh/ton	80	70
Oil consumption	l/ton	0	0
Heat consumption	MJ/ton	0	0
Natural gas consumption	l/ton	0	0
Energy recovery			
Elect. efficiency	%	22	0
Heat efficiency	%	63	80
Emissions			
CO ₂ -biomass	g/ton	200000	200000
CO ₂ -fossil	g/ton	0	0
CO	g/ton	153	92
CH ₄	g/ton	0	0
SO ₂	g/ton	110	127
HCl	g/ton	13	19.5
NO _x	g/ton	1.142	765
NH ₃	g/ton	0	0
N ₂ O	g/ton	0	0
NMVOC	g/ton	0	0
NO ₃	g/ton	-	-
N-tot	g/ton	-	-
P-tot	g/ton	0	0

11. Energy production and allocation between power and district heating

General description

There are two very important aspects in defining the life cycle inventory (LCI) for production of one unit of electricity and district heating. The first aspect is about the technology and energy source and the second on how to allocate resources and emissions from combined power and heating plants. The LCI for energy products is used in calculating the overall resource consumption and emissions whenever electricity and district heating are produced and consumed in the waste management system.

Technology and energy choices

The choice of technology for energy production may have a very significant impact on the overall environmental results. There are two main approaches that can be used for choosing the energy production technology for energy, which is used/produced in a solid waste management system. First, an average approach can be used where the technology is the average in the region or country. This will most often imply that the energy production is a mix of different technologies and energy sources (coal, gas, nuclear, hydro etc.). The second approach is the marginal approach, where either a present or a future marginal technology is used. The present marginal energy source could be natural gas but on long term the marginal energy source would rather be coal (in Denmark), because this is the energy source, which is used when expanding the energy production capacity. The choice of marginal energy sources can however be different in different countries with other energy infrastructure.

However, electricity and district heating are different in the respect that electricity can be transported over very long distances and the choice depends on the approach described above. The situation is very different for district heating where the choice of technology and energy source must rely on the local conditions since district heating cannot with benefit be transported over long distances. This means that the energy technology and source choices must be made for electricity and district heating separately since the energy technology and source may be different for the two energy types.

Allocation between electricity and district heating

Allocation of resources and emissions between electricity and district heating at combined power and heating plants can be done in two main methods. The emissions can either be allocated by the energy content, so one unit of energy has the same emissions for electricity and district heating or allocating is made by the exergy content where the qualities of the energy products are considered. The environmental assessment tool will include only LCI for energy products allocated by the exergy method.

The LCI's for different technologies and energy sources are made by the Danish power company E2 during a comprehensive LCA project on energy production (Energi E2 et al., 2000). The results are presented in Table 11.1. In Table 11.2 the distribution of district heating production are shown from the same examination. The energy sources included in the tool are coal, natural gas in combined cycle, oil, nuclear power, hydropower and wind power. Emissions included are: CO₂, CO, CH₄, SO₂, HCl, NO_x, NH₃, N₂O and NMVOC, defined as g/kWh electricity and g/MJ heat. The user makes a choice of technology for both electricity and heating as either a country mix or one marginal energy source.

The following mixes and energy resources can be chosen for the LCI for electricity.

- a. Denmark, average
- b. Finland, average
- c. Norway, average
- d. Sweden, average
- e. Coal
- f. Natural gas
- g. Oil
- h. Biomass
- i. Nuclear power
- j. Hydro power
- k. Wind power

Table 11.1: Distribution for average electricity production in Nordic countries

%	Coal	Natural gas	Oil	Biomass	Nuclear power	Hydro power	Wind power
Denmark ^a	60	21	6	7	0	0	6
Finland							
Iceland							
Norway							
Sweden							

^aEnergistatistik, 2004)

Table 11.2: Distribution for average district heating production in Nordic countries

%	Coal	Natural gas	Oil	Biomass	Nuclear power
Denmark ^a	29	33	7	31	-
Finland					
Iceland					
Norway					
Sweden					

^aEnergistatistik, 2004)

The technology for district heating production can be chosen from the same list as above with exception of hydro and wind power, which usually do not generate district heating.

12. Transportation of residues

General description

Fuel combustion for transport of residues is the main contribution to potential environmental impacts. Thus, production of vehicles is excluded from the study because impacts from this activity are minor compared to emissions during the use stage of the vehicles.

Input

Fuel consumption is calculated on the basis of the amount of produced residues from pre-treatment and biological treatment and on the user defined transport distances for each produced residue, Table 12.1. Table 4.2 defines the specific energy consumption per ton of material per transported distance. The fuel consumption for each transport is calculated as an energy requirement for which a fuel type and combustion technology should be chosen. It is possible to define for each transport whether the fuel is diesel or methane and which type of engine the fuel is combusted, Table 12.2.

Table 12.1: Transport distances for residues (example)

TRANSPORT	DISTANCE (km)
From pre-treatment to biological treatment plant	10
From pre-treatment to incineration plant	20
From biological treatment plant to incineration	13
From biological treatment plant to use on land	20

Emissions

Emissions occurring due to transport is calculated on the basis of the given life cycle inventories for fuel combustion (Table 12.2) and the required energy requirements.

Table 12.2: LCI for transport fuel combustion

LCI for combustion of diesel and methane	Diesel oil, combusted in Euro3 (Wenzel H., 1997)	Diesel oil, combusted in Euro4 (Wenzel H., 1997)	Methane combustion	Default transport	Unit
Name					
Crude oil	24.25	24.25	0	24.25	g/MJ
Methane	0	0	0.278	0	Nm ³ /MJ
Emissions					
CO ₂	78.9	78.9	0	78.86	g/MJ
CO	0.0	0.0	1	0.01	g/MJ
CH ₄	0.5	0.5	0.003	0.53	g/MJ
SO ₂	0.0	0.0		0.00	g/MJ
HCl	0.9	0.9		0.91	g/MJ
NO _x	0.1	0.1		0.08	g/MJ
NH ₃	0.2	0.2		0.17	g/MJ
N ₂ O	0.1	0.1		0.07	g/MJ
NM VOC	0.1	0.1		0.07	g/MJ

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Sammenfatning

I alle de nordiske lande fokuseres der på affaldsstrategier, som går ud på at minimere affaldsmængderne og på at udnytte de ressourcer, der findes i affaldet. Bedre håndtering af byernes affald er ligeledes i fokus, fordi de udgør en central affaldsfraktion med mange uudnyttede potentialer for forbedret håndtering. I de senere år er der etableret mange fuld-skala systemer med kildesortering af det organiske husholdningsaffald og der er gennemført mange projekter for at opnå den bedst mulige håndtering og udnyttelse af affaldets potentialer. Kompostering og bioforgasning er de teknologier, der er brugt for at behandle den organiske del af husholdningsaffaldet; men omfanget af de to metoder og de tekniske systemer, der er anvendt, er meget forskellig i de nordiske lande.

Resultater fra både fuld-skala systemer og undersøgelser af pilotstudier viser, at økonomien i kildesortering er meget afhængig af indretningen af sorteringssystemet og at den energiproduktion der kommer ud af systemer med bioforgasning, er meget betydningsfuld for den miljømæssige bedømmelse af det samlede system håndtering af husholdningsaffald.

En dansk undersøgelse, som omfattede fire forsøg i stor skala, viste at de miljømæssige fordele ved kildesortering af organisk husholdningsaffald er marginale under danske forhold, hvis alternativet til kildesortering og bioforgasning er forbrænding af husholdningsaffaldet på anlæg med kombineret kraft-varmeproduktion. Hvis derimod forbrændingen sker på anlæg uden kraftvarmeproduktion opnås der væsentlige miljøgevinster ved bioforgasning af den organiske fraktion af husholdningsaffaldet. I en række internationale undersøgelser er kompostering af kildesorteret husholdningsaffald fremhævet som en økonomisk og miljøvenlig håndteringsstrategi og kompostering er også internationalt den mest almindelige metode til behandling af den organiske fraktion af husholdningsaffaldet.

Lokale forhold vil altid spille en væsentlig rolle for valg af system for håndtering af husholdningsaffald. Indsamlingssystem og -strategi, håndteringsmetode, udnyttelse af produkter fra behandlingen og den endelige disponering af restprodukter spiller alle en rolle og lokale forhold kan være meget forskellige. Samtidig kan nationale forhold, herunder politiske prioriteringer, spille en væsentlig rolle for valg af affaldshåndteringssystem.

Et værktøj til lokal beslutningsstøtte vedrørende håndtering af organisk husholdningsaffald må derfor udvikles, således at det dækker det brede spektrum af teknologiske løsninger, der er til rådighed i dag og samtidig inkluderer muligheden for at inddrage nationale og lokale omstændigheder og prioriteringer.

Formålet med det foreliggende projekt har været at udvikle et PC-baseret beslutningsstøttesystem for nordiske kommuner, som ønsker at vurdere de miljømæssige konsekvenser af systemer til indsamling og behandling af den organiske del af husholdningsaffaldet.

Værktøjet skal være anvendeligt til nordiske forhold og det nødvendige datagrundlag skal være realistisk i forhold til de muligheder, den enkelte kommune har for at skaffe tilstrækkeligt gode baggrundsdata uden væsentlige omkostninger.

Beslutningsstøtteværktøjet er lavet i et samarbejde mellem danske og svenske forskere. Gruppen har sammen og hver for sig udført mange projekter knyttet til indsamling, behandling og slutanvendelse af den organiske fraktion af kildesorteret organisk husholdningsaffald, både i nationale projekter, i samfinansierede svensk/danske projekter og i internationale projekter. Samtidig er gruppens medlemmer involveret i udvikling af de livscyklusværktøjer til affaldshåndtering, som er under konstant udvikling både i Sverige og Danmark.

Det udviklede værktøj fokuserer på de mest centrale miljømæssige aspekter uden at tage det nationale eller globale perspektiv. Samtidig er opbygningen enkel for at sikre, at det nødvendige datagrundlag kan skaffes lokalt.

Enkelthed er opnået ved at:

- Rammerne for beslutningsstøtten er begrænset til indsamling, behandling og endelig anvendelse af produkter og restprodukter fra behandling af den organiske fraktion af husholdningsaffaldet. Andre affaldstyper kan inddrages; men værktøjet er ikke indrettet herpå.
- Kun forbrug, emissioner og produkter, der forventes at være af betydning for lokale beslutninger, er inkluderet. Det giver en væsentlig reduktion i antallet af stoffer og processer, der er inkluderet, sammenlignet med mere sofistikerede modeller. Samtidig fører det til en dramatisk reduktion af databehovet.
- Datakravene er begrænset til det mindst mulige og fokus er på tilgængelige informationer fra anlæg i drift, fra litteraturen og fra leverandører. Desuden er basale data indsamlet gennem de senere års mange projekter inkluderet og kan anvendes, hvis de anses for relevante ved den enkelte anvendelse af værktøjet.
- Standarddata som anvendes i værktøjet, men som ikke er relateret til lokale forhold, er inkluderet, således at brugeren kan fokusere på lokale data.

Projektet er finansieret af Nordisk Ministerråd og der har været etableret en styregruppe af medlemmer fra de nordiske miljøstyrelser. Desuden var der til projektet knyttet et ressource-team bestående af medlemmer fra de nordiske affaldsorganisationer.

Appendix

1. General Description

The overall model structure is shown in Figure 1. Here the physical components of the model are shown. The starting point is the organic waste and the collection system. The pre-treatment is necessary in order to handle any missortings and to remove any plastic bags used in the collection. Further the waste is prepared for further treatment. Two main options exist for handling of the waste – composting and biogasification. Further combined processes seem to appear and are included as well. After the biological treatment products such as compost or gas will be utilised and residues from the treatment have to be incinerated or used for agricultural purposes.

Figure 1: System boundaries for Biowaste model

The Biowaste model is developed in Excel and includes following worksheets:

Worksheet names	Description
1. "Input data"	User input. Defining technologies
2. "System assumptions"	Overview of chosen technologies and waste amounts
3. "Mass flows"	Mass and substance flows
4. "LCI"	Life cycle inventory
5. "LCIA"	Life cycle impact assessment results
6. "Chart-LCIA"	Life cycle impact assessment graph
7. "Waste characterisation"	Organic household waste compositions
8. "Technologies"	Collection and waste treatment technologies
9. "Calc. pre-treatment"	Calculation of pre-treatment
10. "Calc. biogas"	Calculation of anaerobic digestion
11. "Calc. compost"	Calculation of composting
12. "Calc. Combined bio treatment"	Calculation of combined biological treatment
13. "Calc. gas use"	Calculation of biogas use
14. "Calc. land use"	Calculation of use of compost or digested organic waste in agriculture
15. "Calc. incineration"	Calculation of incineration
16. "Calc. transport"	Calculation of transportation and collection
17. "LCIA factors"	Life cycle impact assessment factors and normalization factors
18. "Constants"	Energy and density constants
19. "Product LCI's"	Life cycle inventories for power, heat, gas, oil and fertilisers
20. "Names & ID's"	Names and ID's for technologies
21. "Boundaries"	System figure

The manual is subdivided according to the list above and has one chapter for each sheet with the same number and title as the description above.

All technology choices are made in sheet 1 and all waste treatment technology data are defined in sheet 8: "Technologies". Waste composition datasets are made in sheet 7: "Waste characterisation". Sheets called "Calc." are calculation sheets, and NO user input is to be made here. The worksheet tabs are coloured according to the type of worksheet as shown in Figure2.

Bright yellow	Dark green	Light green	Blue	Grey
User input work-sheet	Results (mass flow, LCI etc.)	Technology data worksheets (user input)	Calculation worksheets	Background data

Figure 2: Colour code for worksheet tabs

In the model and in this manual a set of colour codes are used (Figure 3). Bright yellow is used for direct user input to define the desired scenario. Green, light yellow and red codes are technology data, which may be defined by the user to modify or add new technologies. Turquoise and blue codes are transferred and calculated data.

Bright yellow	Green	Light yellow	Red	Turquoise	Blue
User input	Certain data (user input)	Uncertain data (user input)	Very uncertain data (user input)	Transferred data	Calculated
Choosing technologies, distances etc. specific for a scenario	Data for technologies in dataset	Data for technologies in dataset	Data for technologies in dataset	Data transferred due to a chosen technology or between worksheets	Data for technologies in dataset

Figure 3: Colour code for data input

2. Input Sheet

Worksheet: “Input data”

A new waste management scenario is made in the first worksheet where all technology choices are made in input data boxes. The waste amount (ton) is defined in the first box shown in Figure 4.

Waste type	unit	amount
Organic household waste	ton	1000

Figure 4: Give the waste amount (example)

Next a waste composition dataset is chosen together with technologies for the following steps of collection and treatment. (Figure 5).

DEFINE METHODS OF TREATMENT TECHNOLOGIES BY CHOOSING VALUES ACCORDING TO TECHNOLOGY IN BOX BELOW:		
	Choice	Selected technology
Waste composition		Organic waste, default
Treatment method	1	Anaerobic digestion
Pre-treatment technology	6	No pre-treatment
Anaerobic digestion technology		Default biogas plant
Biogas utilisation		Default energy production
Incineration technology		Default incineration
Use of compost/digested material	1	Plant, clay, west DK
Residential areas for collection	1	Single family housing
Transportation methods		Default transport
Power technology/country	5	Coal
Heat technology/country	8	Biomass
Normalisation reference		Normalisation Global

Figure 5: Defining waste types and waste treatment technologies (example)

The choices are defined by a value, which represents a technology corresponding to the number of technologies. If cells are left blank the default technology will be chosen. The list of technologies that can be chosen can be seen in Figure 6. In the list of technologies the value in the left column is the number, which represents the technology in that row.

Value	WASTE COMPOSITION	TREATMENT METHODS	PRE-TREATMENT TECHNOLOGY	ANAEROBIC DIGESTION TECHNOLOGY	COMPOSTING TECHNOLOGY	COMBINED BIO TREATMENT TECHNOLOGY	BIOGAS UTILISATION
1	Organic waste, default	Anaerobic digestion	Default pre-treatment	Default biogas plant	Default composting plant	Default combined bio-treatment	Default energy production
2	Copenhagen, paper bags	Composting	Disc screen	Grindsted, mesophilic	Windrow	Aikan	Grindsted, electricity production
3	Kolding, plastic bags	Combined bio-treatment	Hydraulic screw press	Herning, thermophilic	Closed reactor	Other combined 1	Herning, combined heat & power
4	Vejle, plastic bags	Incineration	Pre-treatment 3	Vaarst-Fjellerad, thermophilic	Home composting	Other combined 2	Vaarst-Fjellerad, combined heat & power
5	Ålborg, plastic bags		Pre-treatment 4	Other biogas 1	Other composting 2	Other combined 3	Upgrade and use in busses
6	Grindsted, paper bags		No pre-treatment	Other biogas 2	Other composting 3	Other combined 4	Other gas use 1
7							
8							
9							
10							
11							

Value	INCINERATION TECHNOLOGY	USE OF BIOMASS/ COMPOST	RESIDENTIAL AREA	TRANSPORTATION METHOD	ENERGY TECHNOLOGIES/ MIX	NORMALISATION REFERENCES
1	Default incineration	Plant, clay, west DK	Single family housing	Default transport	Denmark, average	Normalisation DK
2	CHP	Dairy, clay, west DK	Multi family housing	Diesel oil, combusted in Euro2	Finland, average	Normalisation FIN
3	Heat plant	Pig, clay, east DK	City areas	Diesel oil, combusted in Euro3	Norway, average	Normalisation ICE
4			Urban areas	Methane combustion	Sweden, average	Normalisation NO
5			Mixed residential areas		Coal	Normalisation SWE
6					Natural gas	Normalisation EU
7					Oil	Normalisation Global
8					Biomass	
9					Nuclear power	
10					Hydro power	
11					Wind power	

Figure 6: Possible technologies

Figure 7 shows the box where transportation distances are given. Transport distances are defined for waste collection from collection area to first treatment and for transport of residues.

DEFINE TRANSPORT DISTANCES	
TRANSPORT	DISTANCE (km)
FROM COLLECTION AREA TO PRE-TREATMENT	25
FROM COLLECTION AREA TO INCINERATION	15
FROM PRE-TREATMENT TO BIOLOGICAL TREATMENT	0
FROM PRE-TREATMENT TO INCINERATION	25
FROM BIOLOGICAL TREATMENT TO USE ON LAND	20

Figure 7: Defining transports distances (example)

3. Waste Characterisation

Worksheet: “Waste characterisation”

Waste characterisation of source separated organic household waste includes contents of total solids (TS), volatile solids, lower heating value, methane potential, contents of C, N, P and K. Finally plastic, which may or may not be used in collection shall be given. Figure 8 shows examples of waste composition sets, which all can be altered by the user. The data sets are from a Danish examination (Christensen *et al.*, 2002) and should be replaced by data relevant for the user (data can be punched in, in the yellow area and the names can be changed in the names & id sheet). The choice of waste type in the input data box (Figure 5) defines which composition is chosen. Figure 9 shows an example of a choice.

Chemical composition								
Waste source		Plastic bags for collection	Organic waste, default	Copenhagen, paper bags	Kolding, plastic bags	Vejle, plastic bags	Ålborg, plastic bags	Grindsted, paper bags
Parameter	Unit	Plastic	separation, Method 0	separation, Method 1	separation, Method 2	separation, Method 3	separation, Method 4	separation, Method 5
Total solids (TS)	%	95.0	35.0	29.9	33.6	33.8	31.3	32.3
Volatile solids (VS)	% af TS	95.0	90.7	90.7	82.8	83.1	85.9	87.9
Lower heating value	MJ/kg TS	42.0	19.3	19.3	18.1	18.1	18.5	18.8
Methane potential	L CH ₄ /kg VS	0	450	450	450	450	450	450
Main components								
C	% of VS	50.0	53.6	53.6	59.6	59.2	57.8	55.0
N	% of VS	10.0	3.6	3.6	4.0	4.0	3.9	3.8
P	% of VS	10.0	0.5	0.5	0.3	0.3	0.3	0.4
K	% of VS	5.0	1.0	1.0	0.8	0.8	0.8	1.0
Plastic	%	100.0	0.0	0.8	0.0	0.0	0.0	0.0

Figure 8: Composition of waste types included in the model. Data from Christensen *et al.*, 2000

Chosen waste type		
Organic waste, default		
Source separation, Method 0		
Total solids (TS)	%	35
Water content	%	65
Volatile solids (VS)	%	31.7
Lower heating value, dry ash fr	MJ/kg VS	21.3
Methane potential	l CH ₄ /kg VS	450
Main components		
C	%	17.02
N	%	1.14
P	%	0.16
K	%	0.32
Plastic	%	0

Figure 9: Chosen waste type (example)

4. Technology Datasets

Worksheet: “Technologies”

Besides collection data the worksheet named “Technologies” includes several sets of technologies within pre-treatment, anaerobic digestion, composting, combined bio-treatment, biogas utilisation, compost/digested material application and incineration moving from right to left. The user may edit data in this worksheet. Data available for a specific technology can be added and used in calculations. The number of technologies in each treatment cannot easily be expanded; so adding a new technology is done by changing name and data of an existing technology. The name of a new technology is added by defining the name in the worksheet “Names & ID’s”, Chapter 20, Figure 64 where process data is modified in the worksheet “Technologies”. In the model it is possible to have:

- 6 pre-treatment technologies
- 6 biogas technologies
- 6 composting plants
- 6 combined bio-treatment plants
- 3 incineration plants
- 6 biogas utilisation technologies
- 3 separate utilisation scenarios compost, digested biomass and compost from combined bio-treatment

In the worksheet “Input data” a scenario is created by choosing treatment and technologies for waste and following residues. Chosen technologies are automatically transferred into each calculation worksheet for the treatment. In the following, examples of the transferred data will be shown.

5. Pre-Treatment

Worksheet: “Calc. pre-treatment”

Pre-treatment of source separated organic household waste may be necessary if biological treatment is chosen. The technology dataset for pre-treatment includes power and oil consumption as well as a set of allocation parameters that distribute waste substances to biomass (biological treatment) and to reject (incineration). The allocation parameters distribute each substance in the waste (TS, water, VS, C, N, P, K and plastic) to biomass and to reject. The sheet “Technologies” includes up to six technologies of which one is a non-pre-treatment method having all allocation parameters to 1 to biomass. The box is seen in Figure 10.

Pre-treatment technology		Default pre-treatment
Power consumption	kWh/ton	15.0
Oil consumption	l oil/ton	0.0

Allocation parameters	unit	to biomass	to reject
Total solids (TS)	-	0.63	0.37
Water content	-	0.73	0.27
Volatile solids (VS)	-	0.624	0.376
Lower heating value, dry ash fr	-	1	1
Methane potential	-	1	1
Main components			
C	-	0.634	0.366
N	-	0.634	0.366
P	-	0.64	0.36
K	-	0.667	0.333
Plastic	-	0.05	0.95

Figure 10: Chosen pre-treatment facility (example)

Note: For Lower heating value and Methane potentials the allocation parameter is 1 to both fractions since heating value and potentials are quality parameters and not masses. The allocation is given by the allocation of VS.

Allocation parameters are multiplied with the incoming waste composition contents and the amounts of biomass and reject is calculated as shown in Figure 11 and the energy consumption as shown in Figure 12.

Distribution between biomass and reject	unit	Waste composition		
			Biomass	Reject
Total solids (TS)	ton	350	221	130
Water content	ton	650	475	176
Volatile solids (VS)	ton	317	198	119
Lower heating value, dry ash free	MJ/kg VS	21	21	21
Methane potential	l/kg VS	450	450	450
Main components				
C	ton	170	108	62
N	ton	11	7	4
P	ton	2	1	1
K	ton	3	2	1
Plastic	ton	0	0	0
Total	ton	1000	695	305

Figure 11: Allocation of waste and substances in pre-treatment (example)

Total power and oil consumption is calculated.

Energy calculations		
Power consumption	15000	kWh
Oil consumption	0	l oil

Figure 12: Energy consumptions pre-treatment (example)

The overall life cycle inventory with resource consumptions and emissions due to upstream processes and the process itself is calculated on the basis of the consumptions. The life cycle inventory for pre-treatment is transferred to the life cycle inventory for the overall system as shown in Figure 13. Calculation of the life cycle inventory and transfer to the overall LCI is done for each activity or treatment (but will not be shown in the following).

LIFE CYCLE INVENTORY

Input	Power	Heat	Oil	Natural gas	Substituted fertiliser	Process specific emissions	Total	
Coal	6966000		0				6966000.0	g
Oil	108000		0				108000.0	g
Natural gas	27000		0				27000.0	g
Orimulsion	0		0				0.0	g
Biomass	0		0				0.0	g
Waste	0		0				0.0	g
Biogas								Nm3
Energy in/out	190506.6		0				190506.6	g
Emissions								
CO ₂ -bio	0		0				0.0	g
CO ₂ -fossil	11232000		0				11232000.0	g
CO	2278.8		0				2278.8	g
CH ₄	20628		0				20628.0	g
SO ₂	4185		0				4185.0	g
HCl	23.76		0				23.8	g
NO _x	7560		0				7560.0	g
NH ₃	0.54		0				0.5	g
N ₂ O	14.04		0				14.0	g
NM VOC	388.8		0				388.8	g
NO ₃ -N	0.06156		0				0.1	g
N-tot	232.2		0				232.2	g
P-tot	0.0108		0				0.0	g

Figure 13: LCI for pre-treatment (example)

6. Anaerobic Digestion

Worksheet: “Calc. biogas”

Anaerobic digestion, or biogasification, has the purpose of producing biogas from organic household waste. This requires energy input (fuel, power and heat) and the yield depends on the organic content (VS) of the waste, the specific methane potential of the waste, and of the degradation ratio for VS for the given biogas plant. The degradation ratio defines how much of the methane potential that is obtained during digestion. Figure 14 shows an example of the needed data. Figure 15 shows the calculation of sediments and floating material that is removed prior digestion.

Chosen biogas plant technology

BIOGAS PLANT		Default biogas plant Biogas plant, Technology 0
Volatile solids degradation	% of VS	75
Fuel consumption	l/ton	0
Electricity consumption	kWh/ton	25
Heat consumption	GJ/ton	0.21
Temperature in digester	°C	55
Heat loss	%	10
Sediment	%	1
Floating material	%	1

Figure 14: Chosen biogas plant (example)

Sediment and floating material is calculated and removed prior to digestion.

CALCULATION OF INPUT, SEDIMENT AND FLOATING MATERIAL					
Input to biogas		IN		OUT	
	Unit			Sediment, 1%	Floating mat. 1 %
Total solids (TS)	t	221		2.21	2.21
Water content	t	475		4.75	4.75
Volatile solids (VS)	t	198.09		1.98	1.98
Lower heating value, dry ash free	MJ/kg VS	21.28		-	-
Methane potential	l/kg VS	450.00		-	-
Main components					
C	ton	107.88		1.08	1.08
N	ton	7.25		0.07	0.07
P	ton	1.02		0.01	0.01
K	ton	2.12		0.02	0.02
Plastic	ton	0.00		0.00	0.00
Total	ton	695		6.95	6.95

Figure 15: Calculation of sediment and floating material (example)

The input to the digester is shown in Figure 16.

INPUT TO ANAEROBIC DIGESTION AFTER SEDIMENTATION		
	Unit	Into digester
Total solids (TS)	ton	216.09
Water content	ton	465.01
Volatile solids (VS)	ton	194.13
C	ton	105.72
N	ton	7.10
P	ton	1.00
K	ton	2.08
Plastic	ton	0.00
Total	ton	681.10

Figure 16: Input to digester after sediment and floating material is removed (example)

The volume of produced methane and the energy content is calculated and shown in Figure 17. The produced methane is transferred to the worksheet “Calc. biogas use”.

GAS PRODUCTION	unit	value
Methane production	Nm ³ CH ₄	65518
Energy potential	MJ	2352562

Figure 17: Gas production from digester (example)

Energy consumptions are calculated on the basis of the technology data and waste input amount as shown in Figure 18.

ENERGY CALCULATIONS	unit	value
Fuel consumption	l	0
Electricity consumption	kWh	17028
Heat consumption	MJ	141129

Figure 18: Energy consumption, biogas plant

Output is calculated on the basis of the biogas production as shown in Figure 19 and the digested biomass is transferred to the worksheet “Calc. land use”.

OUTPUT CALCULATION	value	unit
Biogas amount	ton	113
Dry matter, out	ton	103
Water, out	ton	465
Total, out	ton	568

Figure 19: Biogas and residue calculation (example)

7. Composting

Worksheet: “Calc. compost”

Composting of source separated household waste produces compost, which can be used as fertiliser/soil amendment. Composting requires energy and emissions are produced during the process. Figure 20 shows an example of the needed data.

COMPOSTING PLANT		Default composting plant Composting plant, Technology 0
Fuel consumption	l/ton	12.5
Electricity cons.	kWh/ton	22
N loss	of N total	20%
Degradation ration of org. matter	of VS	50%
DM in output	TS	30%
Gas cleaning?		NO
Methane production	C-loss	2.00%

Figure 20: Chosen composting plant (example)

For composting there are defined some general data concerning nitrogen emissions, VOC emissions and cleaning efficiencies if there is a gas cleaning system at the composting plant. These data are defined in worksheet “Technologies”. If no gas cleaning exists, cleaning efficiencies are zero. An example of the general emission parameters is shown in Figure 21.

General parameters for all composting technologies

Distribution of N-loss	NH3	N2O	N2	Sum
% of total loss	96%	2%	2%	100%
VOC loss				
% of lost CO ₂ -C	2%			
Gas cleaning				
% of the formed gaseous substance removed from the gas				
	NH3	N2O	CH4	
% removal	95%	0%	50%	
N-distribution in output	NH3	NO3	Org.N	Sum
% of N total in output	1%	6%	93%	100%

Figure 21: General emission parameters for C and N from composting (example)

Input to composting and the composition of the final compost is calculated on the basis of the given data above as shown in Figure 22. The produced compost is transferred to the worksheet “Calc. land use”.

INPUT & OUTPUT				
Input to Composting		IN		OUT
	Unit	Organic waste		Compost
Total solids (TS)	ton	220.50		121.5
Water content	ton	474.50		283.4
Volatile solids (VS)	ton	198.09		99.0
Lower heating value, dry ash free	MJ/kg VS	21.28		
Methane potential	l/kg VS	450.00		
C	ton	107.88		53.94
N	ton	7.25		5.80
P	ton	1.02		1.02
K	ton	2.12		2.12
Total	ton	695.00		404.85

Figure 22: Input and output from composting (example)

Nitrogen emissions (before possible gas cleaning) are calculated as shown in Figure 23.

Distribution of N-loss	NH3	N2O	N2	Sum
kg N	1391.1	29.0	29.0	1449.1
kg substance	1689.2	45.54	29.0	-
kg substance emitted	1689.2	45.54	-	-

Figure 23: N-emissions from composting

Methane emissions are calculated as seen in Figure 24 on the basis of the carbon loss during composting and the methane factor (Figure 20) for the given technology.

Methane loss		
Methane produced	kg CH4	1438.36
Methane emitted after cleaning	kg CH4	1438.36
VOC produced	kg VOC-C	1078.77

Figure 24: Methane emissions, composting (example)

Finally the energy consumptions calculation is made as seen in Figure 25.

ENERGY CONSUMPTION	unit	value
Electricity consumption	kWh	15290
Oil consumption	l	8688

Figure 25: Energy consumption, composting (example)

8. Combined Biological Treatment

Worksheet: “Calc. combined biotreat”

Combined biological treatment is a combination of anaerobic digestion followed by a composting process of organic waste. An example of the needed data is shown in Figure 26. It is seen that there is a production of biogas, emissions from composting and a compost material that can be used for land application. Biogas production is defined by the degradation ratio, methane emissions by a fraction of the overall carbon loss (as composting) and nitrogen emissions from general factors that apply for all combined bio-treatment technologies (Figure 27).

COMBINED BIOLOGICAL TREATMENT		Default combined bio-treatment Combined bio-treatment, Technology 0
Fuel consumption	l/ton	0
Electricity cons.	kWh/ton	0
N loss	of N total	50%
Degradation ration of org. matter	VS	45.0%
DM in output	TS	30.0%
Gas cleaning?		NO
Methane production	C-loss	2.00%

Figure 26: Chosen combined biological treatment (example)

Distribution of N-loss	NH3	N2O	N2	Sum
% of total loss	96%	2%	2%	100%
VOC loss				
% of lost CO2-C	2%			
Gas cleaning				
% of the formed gaseous substance removed from	NH3	N2O	CH4	
% removal	95%	0%	50%	
N-distribution in output	NH3	NO3-N	Org.N	Sum
% of N total in output	1%	6%	93%	100%

Figure 27: General emission parameters for C and N from combined bio-treatment (example, from “Technologies”)

Input to the combined bio-treatment is calculated as well as the compost composition on the basis of degradation ratio and nitrogen emissions as shown in Figure 28. The produced compost is transferred to the worksheet “Calc. land use”.

Figure 28: input and output from combined bio-treatment (example)

INPUT & OUTPUT				
Input to combined biotreatment		IN		OUT
	unit	Organic waste		Compost
Total solids (TS)	ton	220.50		131.4
Water content	ton	474.50		306.5
Volatile solids (VS)	ton	198.09		108.9
Lower heating value, dry ash free	MJ/kg VS	21.28		
Methane potential	l/kg VS	450.00		
C	ton	107.88		48.54
N	ton	7.25		3.62
P	ton	1.02		1.02
K	ton	2.12		1.06
Total	ton	695.00		437.87

Nitrogen emissions are calculated as shown in Figure 29.

Distribution of N-loss	NH3	N2O	N2	Sum
kg N	3478	72	72	3623
kg substance	4223	114	72	-
kg substance emitted	4223	114	-	-

Figure 249: N-emissions, combined bio-treatment (example)

Methane emissions after possible cleaning are calculated as shown in Figure 30.

Methane loss	unit	
Methane loss	kg CH4	1582
Methane emitted after cleaning	kg CH4	1582
VOC produced	kg VOC-C	72

Figure 30: Methane emissions, combined bio-treatment (example)

Energy consumptions and methane for further utilisation is calculated as shown in Figure 31 and the produced methane is transferred to the worksheet “Calc. gas use”.

ENERGY CALCULATIONS		unit
Electricity consumption	kWh	0
Oil consumption	l	0
GAS PRODUCTION		
Produced methane	m3 CH4	40113
Energy potential	MJ	1440344

Figure 31: Energy consumption and methane production (example)

9. Biogas Utilisation

Worksheet: “Calc. gas use”

Biogas produced either at a biogas plant or a combined biological treatment plant will be transferred to the worksheet “Calc. biogas use”. This sheet enables biogas to be used for electricity and/or district heating production or for use for transportation. Electricity and heat produced will substitute the chosen energy source (in “Input Data”) where if biogas is used for transportation, diesel fuel combustion is substituted. An example of the chosen biogas utilisation is shown in Figure 32.

Biogas utilisation		Default energy production Biogas energy plant, Technology 0
Electricity consumption of upgrading	kWh/Nm ³ CH ₄	0
Total energy recovery rate	%	85
Power recovery rate	%	38
Heat recovery rate	%	47
Unburned methane emission	% of methane	3
Methane percentage in biogas	%	65
CO ₂	g/MJ	0
NO _x	g/MJ	0
SO _x	g/MJ	0
CO	g/MJ	0
Energy use for transportation	MJ/km	0

Figure 32: Chosen biogas utilisation (example)

The amount of methane is transferred from either anaerobic digestion calculations or combined bio-treatment calculations. The consumption for possible upgrading is calculated and if electricity and heat is produced, these are calculated on the basis of the heating value of methane (“Constants”). The amount of unburned methane from the biogas combustion technology is calculated. The calculations are shown in Figure 33.

Produced biogas from:		Anaerobic digestion
Methane produced	Nm3	65518
Electricity consumption	kWh	0
Energy in biogas	MJ	2352562
Energy out, gross production	MJ	1999678
Electricity surplus	kWh	248326
Heat surplus	MJ	1105704
Unburned methane emission	kg	1367

Figure 33: Energy calculation, biogas utilisation (example gas use for power and heat production)

Emissions are calculated (both if used for power and heat and for use for transport). If biogas is used for transport the amount of substituted diesel is calculated by the energy content of biogas and the energy content of diesel considering the energy efficiency of bus or truck engines are the same regardless if biogas or diesel is the used fuel. An example of the calculations is shown in Figure 34.

Emissions		
NOx	g	0
SOx	g	548147
CO	g	0
Transport distance	km	189723
Substituted diesel oil	l	65589

Figure 34: Emissions and possible transport utilisation (example gas use in busses)

10. Use F Compost or Digested Material

Worksheet: “Calc. land use”

Digested biomass and compost produced from composting or combined biological treatment can be utilised in agriculture and thereby substitute commercial fertilisers by the content of nitrogen, phosphorous and potassium (NPK). Thereby emissions due to production of commercial fertilisers and emissions due to the content of heavy metals in fertilisers are avoided. An example of input data is given in Figure 35.

INPUT		
	unit	IN Digested biomass
Total solids (TS)	ton	103.0
Water content	ton	465.0
Volatile solids (VS)	ton	81.1
Main components		
C	ton	105.72
N	ton	7.10
P	ton	1.00
K	ton	2.08
Total	ton	568

Figure 35: Input to land application (example)

By using compost or digested biomass there may arise higher nitrogen emissions than by using commercial fertiliser. The extra emissions by use of organic matter compared to the use of commercial fertiliser depend very much on the soil type, precipitation, farm type and animal density (Bruun & Stoumann Jensen). An example of calculations is given in Figure 36.

Nitrogen emissions from use of degasified biomass		Plant, clay, west DK
NO ₃ -N	of N-tot biomass	37%
NH ₃	of N-tot in biomass	8%
N ₂ O	of N-tot in biomass	1%
NO ₃ -N	kg	2627
NH ₃	kg	647
N ₂ O	kg	156

Figure 36: Extra emission factors by using compost/biomass instead of commercial fertiliser (example)

11. Incineration

Worksheet: “Calc. incineration”

Incineration of waste often requires power and fuel consumption for start-up and possibly to keep the temperature at a desired level. It is assumed that organic household waste is incinerated together with residual waste thus no technical problems should occur. Important factors for incineration is power consumption, oil and gas consumption and the energy efficiency. An example of the needed basic data is given in Figure 37.

INCINERATION PLANT		Default incineration
Power consumption	kWh/ton	80
Oil consumption	l/ton	0
Heat consumption	GJ/ton	0
Natural gas consumption	Nm3/ton	0.12
Total energy recovery efficiency	%	80
Elect. efficiency	%	18
Heat efficiency	%	62
Unburned VS	%	4
Air Pollution Control residue production	%	5

Figure 37: Chosen incineration technology (example)

Emissions from incineration are defined per ton of organic waste incinerated. These process specific emissions are defined for each incineration technology in “Technologies” and an example are shown in Figure 38.

Process specific air emissions		
CO ₂ -bio	500	g/ton
CO ₂ -fossil	0	g/ton
CO	1	g/ton
CH ₄	1	g/ton
SO ₂	18	g/ton
HCl	5	g/ton
NO _x	10	g/ton
NH ₃	5	g/ton
N ₂ O	0	g/ton
NM VOC	10	g/ton
NO ₃ -N	0	g/ton
N-tot	0	g/ton
P-tot	0	g/ton

Figure 38: Process specific emissions from chosen incineration technology (example)

Waste to incineration can be either directed from pre-treatment where a reject is produced or waste can be led directly to incineration if no biological treatment is chosen. Figure 39 shows an example of the input data.

INPUT & OUTPUT						
		Reject from pre-	Waste directly to	Total	Residuals	
		treatment	incineration			
Total solids (TS)	ton	129.50	0.0	129.50		21
Water content	ton	175.50	0.0	175.50		-
Volatile solids (VS)	ton	119.36	0.0	119.36		-
Lower heating value, dry ash free	MJ/kg VS	21.3	0.0	21.3		-
Methane potential	l CH ₄ /kg VS	450	450			-
Main components						
C	ton	62.28	0.0	62.28		-
N	ton	4.18	0.0	4.18		-
P	ton	0.57	0.0	0.57		-
K	ton	1.06	0.0	1.06		-
Plastic	ton	0.00	0.0	0.00		-
Total	ton	305	0	305		-

Figure 39: Input to incineration (example)

Power consumption and use of fuels are calculated as well as the produced power and/district heating. The electricity and district-heating surplus calculated below in Figure 40 are the net productions or energy that can be sold to the market. These amounts of electricity and heat substitute external production of electricity and heat.

ENERGY CALCULATIONS		
Energy in	GJ	2110
Energy out, gross	GJ	1688
Electricity out, gross	GJ	380
District heating out, gross	GJ	1308
Electricity consumption	GJ	88
Heat consumption	GJ	0
Oil consumption	l	0.0
Natural gas consumption	Nm3	36.6
Electricity surplus	kWh	81095
District heating surplus	GJ	1308

Figure 40: Energy balance for incineration of organic waste (example)

Emissions from incineration are calculated on the basis of data in Figure 40 and the results are shown in Figure 41.

Air emissions	unit	value
CO2-bio	g	152.5
CO2-fossil	g	0
CO	g	0.305
CH4	g	0.1525
SO2	g	5.49
HCl	g	1.525
NOx	g	3.05
NH3	g	1.525
N2O	g	0.00305
NM VOC	g	3.05
NO3-N	g	0
N-tot	g	0
P-tot	g	0

Figure 41: Process specific emissions from incineration (example)

12. Transportation

Worksheet: “Calc. transport”

The worksheet “Calc. transport” calculates the total energy demand and emissions due to collection of waste and due to transport of waste and residues. In Figure 42 the energy demand is calculated for collection and transport to first treatment, and of biomass and reject from pre-treatment to biological treatment and incineration respectively and finally for transport of compost or digested biomass from biological treatment to land application. Distances given are transferred from “Input data” worksheet.

Transportation technology:		Default transport		
TRANSPORT	0	ton	DISTANCE (km)	Fuel consumption MJ
COLLECTION AND TRANSPORT TO PRE-TREATMENT	A-B	1000	25	296000
COLLECTION AND TRANSPORT TO INCINERATION	A-F	0	15	0
FROM PRE-TREATMENT TO BIOLOGICAL TREATMENT	0	695	0	0
FROM PRE-TREATMENT TO INCINERATION	0	305	25	18300
FROM BIOLOGICAL TREATMENT TO USE ON LAND	0	568	20	27266
TOTAL				341566

Figure 42: Fuel consumption for collection and transportation of all residues (example)

Fuel demand for collection may depend on the type of collection system and may be different for collection of residual waste and for source separated organic household waste. Figure 42 defines fuel consumption for collection of organic waste both when collected with residual waste (“Traditional collection”) and when source separated organic household waste is collected separately (“Separate collection”).

Type of residential area	Fuel consumption		
	Traditional collection	Seperate collection	
Single family housing	118	236	MJ/ton
Multi family housing	118	236	MJ/ton
City areas	118	236	MJ/ton
Urban areas	250	500	MJ/ton
Mixed residential areas	144	288	MJ/ton

Fuel consumption for transport	2.4	MJ/ton/km
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Figure 43: Fuel demand for collection of source organic household waste (example, from “Technologies” worksheet)

There exist four technologies for fuel combustion, which is chosen in “Input data” worksheet. Resource consumption and emissions are defined per MJ used in transportation as shown in Figure 44.

LCI for combustion of 1 MJ for transportation	Diesel oil, combusted in Euro2	Diesel oil, combusted in Euro3	Methane combustion	Default transport	Unit
Name					
Crude oil	25.4	23.5	0	23.5	g/MJ
Methane	0	0	0.0278	0	Nm3/MJ
Energy	1.09	1.00	1.00	1.00	MJ
Emissions					
CO-bio	0.000	0.0	0.0	0.0	g/MJ
CO2-fossil	84.20	78.9	0.0	81.5	g/MJ
CO	0.204	0.0	1.0	0.1	g/MJ
CH4	0.104	0.5	0.0	0.3	g/MJ
SO2	0.060	0.0		0.0	g/MJ
HCl	0.000	0.9		0.5	g/MJ
NOx	0.714	0.1		0.4	g/MJ
NH3	0.000	0.2		0.1	g/MJ
N2O	0.003	0.1		0.0	g/MJ
NM VOC	0.201	0.1		0.1	g/MJ
NO3-N	0.001	0.0	0.0	0.0	g/MJ
N-tot	0.001	0.0	0.0	0.0	g/MJ
P-tot	0.000	0.0	0.0	0.0	g/MJ

Figure 44: Resources use and emissions for different transportation technologies (example)

The total resources and emissions due to the energy demand and the chosen combustion and fuel technology (Figure 44) is calculated and transferred to the life cycle inventory for the system.

13. System Assumptions

Worksheet: “System assumptions”

This worksheet (“System assumptions”) serves as a check for the user to control that the chosen technologies and amounts of waste to each treatment is according to the users wishes. An example is shown in Figure 45.

SYSTEM DESCRIPTION				
Technologies and waste treatment				
Processes	Unit	Value	Technology	Comment
Waste	ton	1000	Organic waste, default	
Pre-treatment	ton	1000	Default pre-treatment	
Biogas facility	ton	695	Default biogas plant	
Combined biotreatment	ton	0	Default combined bio-treatment	
Biogas utilisation	1000 m3	65518	Upgrade and use in busses	
Composting	ton	0	Default composting plant	
Incineration	ton	305	Default incineration	
Use of compost	ton	568	Plant, clay, west DK	
Waste collection area	-	-	Single family housing	
Transportation	-	-	Default transport	
Power production	-	-	Coal	
District heating production	-	-	Biomass	
Normalisation reference	-	-	Normalisation Global	

Figure 45: Overall system assumptions made by user (example)

14. Mass And Substance Flows

Worksheet: “Mass flows”

This worksheet gives the user an overview of the mass flow and substance flow to each treatment in the scenario from waste generation to pre-treatment, biological treatment, use of compost/digested material and incineration. An example is shown in Figure 46.

	Organic household waste	Waste to pre-treatment	Waste to biogas plant	Reject from biogas plant	Waste to composting	Waste to combined biotreatment	Biogas to utilisation	Compost/ biomass to land use	Organic waste directly to incineration	Reject from pre-treatment to incineration	Total to incineration	Residue from incineration
ton	1000	1000	695.00	13.90	0.00	0.00		568.03	0.00	305.00	318.90	21.39
ton	350.00	350	220.5	4.41	0.00	0.00		103.02	0.00	129.50	133.91	21.39
ton	650.00	650	474.5	9.49	0.00	0.00		465.01	0.00	175.50	184.99	-
ton	317.45	317.45	198.0888	3.96	0.00	0.00		81.06	0.00	119.36	123.32	-
MJ/kg VS	21.28								0.00	21.28		
l CH4/kg VS	450.00											
ton	170	170	107.88	2.16	0.00	0.00		105.72	0.00	62.28	64.43	-
ton	11.43	11.43	7.25	0.14	0.00	0.00		7.10	0.00	4.18	4.33	-
ton	1.59	1.59	1.02	0.02	0.00	0.00		1.00	0.00	0.57	0.59	-
ton	3.17	3.17	2.12	0.04	0.00	0.00		2.08	0.00	1.06	1.10	-
ton	0.0	0.0	0.00	0.00	0.00	0.00			0.00	0.00	0.00	-
Nm3							65517.87					

Figure 46: Mass flow and substance flow (example)

15. Life Cycle Inventory

Worksheet: “LCI”

The life cycle inventory for the total scenario includes a quantification of resource consumption and emissions from each of the activities in the scenario. Resources are quantified for energy resources since these are usually the most significant resources when assessing solid waste systems for organic municipal waste. The energy resources are calculated into primary energy (MJ), which describes the energy content of the consumed energy resources. The emissions that are quantified are the main substances that contribute to the main environmental impact potentials that are calculated below in Figure 47.

SCENARIO		Anaerobic digestion						
		Pre-treatment	Anaerobic digestion	Use of biogas	Use of compost/biomass	Incineration	Collection and transport	Total
Resources		Default pre-treatment	Default biogas plant	Upgrade and use in busses	Plant, clay, west DK	Default incineration	Default transport	
Coal	g	6.97E+06	7.91E+06	6.01E+07	-1.25E+06	-3.77E+07		3.60E+07
Oil	g	1.08E+05	1.88E+05	-5.89E+07	-1.69E+06	-1.19E+06	8.03E+06	-5.34E+07
Natural gas	g	2.70E+04	3.54E+04	-3.07E+06	-7.30E+06	-1.51E+05		-1.05E+07
Orimulsion	g	0.00E+00	0.00E+00	0.00E+00	-1.57E+06	0.00E+00		-1.57E+06
Biomass	g	0.00E+00	6.35E+06	-6.89E+04	0.00E+00	-5.89E+07		-5.26E+07
Waste	g	0.00E+00	2.35E+05	0.00E+00	0.00E+00	-2.18E+06		-1.95E+06
Biogas	Nm3	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Energy in/out	MJ	1.91E+05	3.14E+05	-1.07E+06	-4.99E+05	-1.93E+06	3.43E+05	-2.65E+06
Emissions								
CO2-bio	g	0.00E+00	0.00E+00	0.00E+00	0.00E+00	1.53E+02	0.00E+00	1.53E+02
CO2-fossil	g	1.12E+07	1.30E+07	-1.00E+08	-3.00E+07	-6.28E+07	2.78E+07	-1.41E+08
CO	g	2.28E+03	3.13E+04	-4.59E+05	-1.92E+04	-2.78E+05	3.56E+04	-6.87E+05
CH4	g	2.06E+04	2.35E+04	1.30E+06	-8.37E+03	-1.12E+05	1.09E+05	1.34E+06
SO2	g	4.19E+03	1.42E+04	4.44E+05	-7.80E+04	-1.10E+05	1.02E+04	2.85E+05
HCl	g	2.38E+01	2.85E+03	-4.63E+01	-9.08E+02	-2.63E+04	1.55E+05	1.30E+05
NOx	g	7.56E+03	2.13E+04	-1.61E+06	-1.10E+05	-1.58E+05	1.35E+05	-1.72E+06
NH3	g	5.40E-01	1.27E+00	-5.53E+02	6.12E+05	-7.50E+00	2.95E+04	6.41E+05
N2O	g	1.40E+01	2.53E+01	-6.03E+03	2.74E+04	-1.48E+02	1.19E+04	3.31E+04
NM VOC	g	3.89E+02	6.77E+02	-4.69E+05	-1.43E+03	-4.28E+03	4.57E+04	-4.28E+05
NO3-N	g	6.16E-02	1.03E-01	-1.97E+03	2.63E+06	-6.38E-01	0.00E+00	2.63E+06
N-tot	g	2.32E+02	2.64E+02	8.08E+02	0.00E+00	-1.26E+03	0.00E+00	4.89E+01
P-tot	g	1.08E-02	1.23E-02	-2.61E+01	-4.48E+04	-5.84E-02	0.00E+00	-4.48E+04

Figure 47: Overall life cycle inventory (example)

16. Life Cycle Impact Assessment

Worksheet: “LCIA”

The tool for evaluation of environmental impacts of source separated organic household waste management uses a simplified method for life cycle assessment. The life cycle method that the environmental impact assessment is based on is the Danish EDIP method (Wenzel, 1997).

- Global warming potential
- Acidification
- Nutrient enrichment
- Photo chemical ozone formation

The environmental impact factors are given below in Figure and values from the LCI (Figure) are used to calculate the environmental impact potentials in Figure.

SCENARIO		Anaerobic digestion					
		Pre-treatment	Anaerobic digestion	Use of biogas	Use of compost/digested material	Incineration	Collection and transport
		Default pre-treatment	Default biogas plant	Upgrade and use in busses	Plant, clay, west DK	Default incineration	Default transport
Characterised potentials							
Global warming	g CO2-eq	1.2E+07	1.4E+07	-7.0E+07	-2.2E+07	-6.6E+07	3.4E+07
Acidification	g SO2-eq	9.5E+03	3.2E+04	-6.9E+05	1.0E+06	-2.4E+05	3.0E+05
Nutrient enrichment	g NO3-eq	1.1E+04	3.0E+04	-2.2E+06	1.2E+07	-2.2E+05	2.9E+05
Photo chemical ozone formation	g C2H4-eq	4.1E+02	1.4E+03	-2.4E+05	-1.3E+03	-1.1E+04	2.5E+04
Normalised potentials							
		Pre-treatment	Anaerobic digestion	Use of biogas	compost/digested material	Incineration	Collection and transport
Global warming	PE	1	2	-8	-2	-8	4
Acidification	PE	0	1	-12	17	-4	5
Nutrient enrichment	PE	0	0	-23	129	-2	3
Photo chemical ozone formation	PE	0	0	-11	0	-1	1
		Total					

Figure 48: Overall life cycle impact assessment

A graphical view (Figure 49) is made in the worksheet “Chart-LCIA” illustrating how each activity contributes to each environmental impact potential.

Figure 49: Graph for LCIA

The Biowaste model enables the user to make a quick comparison between anaerobic digestion, composting, combine bio-treatment and incineration with the same assumptions made in “Input data”. Pressing following button shown in Figure 50, which commences a macro modelled in Visual Basic, makes the comparative scenario calculation. The macro button is placed in “LCIA”.

Figure 50: Scenario calculation button

When pressing the macro button a form appears (Figure 51) where the user should define the technologies for biological treatment and incineration for the comparative calculation. The technologies that can be chosen are transferred from the worksheet “Input data”, Figure 6, thus when technologies are modified or changed and given new names, these will be used in the form below. If no technology is marked under a treatment method, the model will use the default technology. When all technologies are chosen the “Calculate scenarios” button is pressed, and results will appear in the worksheet “LCIA”.

Choose biological treatment technologies

Choose biological treatment technologies for comparative scenarios

Calculate scenarios

Cancel

Biogas technologies

☐ Grindsted, mesophile
 ☐ Vaarst-Fjellerad, thermofile

☐ Herning, thermofil
 ☐ biogas4

☐ biogas5
 ☐ Default biogas plant

Composting technologies

☐ Windrow
 ☐ other 1

☐ Closed reactor
 ☐ other 2

☐ biogas5
 ☐ Default biogas plant

Combined bio-treatment technologies

☐ Aikan
 ☐ other 2

☐ Other 1
 ☐ other 3

☐ biogas5
 ☐ Default biogas plant

Incineration technologies

☐ CHP
 ☐ Default incineration

☐ Heat plant

If no technology is chosen, default technology is used.

Figure 51: Form for defining technologies for comparative scenario calculation

Results from comparative scenario calculation are given in Figure 52 and Figure 53.

	Unit	Biogas	Compost	Combined biotreatment	Incineration
Technologies:		Default biogas plant	Default composting plant	Default combined bio-treatment	Default incineration
Global warming	PE	-21	6	-6	-23
Acidification	PE	14	149	134	-5
Nutrient enrichment	PE	163	244	231	-7
Photo chemical ozone formation	PE	2	3	2	1
Energy total	MJ	-5.24E+06	-1.22E+06	-3.94E+06	-4.66E+06

Figure 52: Scenario calculation results

17. Life Cycle Impact Factors and Normalisation Factors

Worksheet: “LCIA factors”

The worksheet “LCIA factors” includes two sets of data: environmental impact factors (Figure 54) and normalisation factors (Figure 55).

Environmental impact factors contribute to evaluate the potential impacts of global warming, acidification, nutrient enrichment and photochemical ozone formation. The unit for each of these impact potentials are grams of an equivalent emission (CO₂, SO₂, NO₃-N and C₂H₄). These factors are from the Danish LCA method EDIP. (Wenzel H., 1997)

Environmental impact factors

	Global warming g CO ₂ -eq/g	Acidification g SO ₂ -eq/g	Nutrient enrichment g NO ₃ -eq/g	Photo ch. ozone form. g C ₂ H ₄ -eq/g
CO ₂ -bio	0			
CO ₂ fossil	1			
CO	2			0.03
CH ₄	25			0.007
SO ₂		1		
HCl		0.88		
NO _x		0.7	1.35	
NH ₃		1.88	3.64	
N ₂ O	320			
NMVOC				0.5
NO ₃ -N			4.43	
N-tot			4.43	
P-tot			32.03	

Figure 54: Environmental impact factors

For an easier comparison between environmental impacts potential it is necessary to evaluate the impacts given in the same unit. This can be done by normalising the impact potentials by the average impact from an average person in a given area. Since global warming is a global environmental effect, the normalisation reference should be an average global person, i.e. the total emission of CO₂ equivalents on the Earth divided by the number of people on the Earth. The remaining environmental impacts are regional to local and the normalisation depends on the emission of substances contributing to each impact in the given region. Normalisation references for Denmark, Europe and for the Earth is given in Figure 55.

The last line shows which normalisation reference that is chosen in the input data box (Figure 5).

Normalisation factors for environmental impacts (if none is given, DK values will be used)

	Global warming	Acidification	Nutrient enrichment	Photo- chemical ozone formation
	kg CO ₂ -eq per person per year	kg SO ₂ -eq per person per year	kg NO ₃ -N-eq per person per year	kg C ₂ H ₄ -eq per person per year
Normalisation DK	8700	101	260	20
Normalisation FIN				
Normalisation ICE				
Normalisation NO				
Normalisation SWE				
Normalisation EU	8700	74	119	25
Normalisation Global	8700	59	95	22
Chosen normalisation reference:				
Normalisation Global	8700	59	95	22

Figure 55: Normalisation factors

18. General Assumptions

Worksheet: “Constants”

This worksheet shown in Figure 56 includes physical constants on heating values, densities and CO₂ emissions from fuels.

General assumptions	unit	value	name Comments, source etc.
Water			
Evaporation heat, water	GJ/ton	2.45	Hfd.vand
Heat capacity, water	MJ/ton/°C	4.186	cp.vand
Density	ton/m ³	1	rho.vand
Energy resources			
Lower heating value			
Oil/diesel	GJ/ton	42.7	Hu.olie Energistatistik 2003 (Danish Energy Authority)
Natural gas	GJ/thousand Nm ³	39.9	Hu.gas Energistatistik 2003 (Danish Energy Authority)
Natural gas	GJ/kg	48	Hu.gas2 Wenzel, 1997
Coal	GJ/ton	26.5	Hu.kul Energistatistik 2003 (Danish Energy Authority)
Lignite	GJ/ton	18.3	Energistatistik 2003 (Danish Energy Authority)
Orimulsion	GJ/ton	27.6	Hu.orimulsion Energistatistik 2003 (Danish Energy Authority)
Waste	GJ/ton	10.4	Hu.affald Energistatistik 2003 (Danish Energy Authority)
Methane	GJ/thousand Nm ³	35.91	Hu.metan Steinmüller Taschenbuch, 25 Auflage, 1992
Fertiliser	GJ/ton	50.01	Steinmüller Taschenbuch, 25 Auflage, 1992
Biomass	kg/kg N	87.8	H.N Production of NH ₃ : 74,56 MJ/kg upper heating value, source: APME.
	GJ/ton	14.5	Hu.biomass straw, Energistatistik 2004 (Danish Energy Authority)
CO₂-emissions (kg CO₂)			
Oil/diesel	kg/GJ	74	CO ₂ .olie Energistatistik 2003 (Danish Energy Authority)
Natural gas	kg/GJ	56.9	CO ₂ .gas Energistatistik 2003 (Danish Energy Authority)
Biogas	kg/GJ	0	CO ₂ .biogas Energistatistik 2003 (Danish Energy Authority)
Waste	kg/GJ	0	CO ₂ .affald Energistatistik 2003 (Danish Energy Authority)
Methane	kg/Nm ³	20	CO ₂ .methan
Fertiliser	kg/kg N	5.2	CO ₂ .N Production of NH ₃ : 4,3 kg CO ₂ /kg NH ₃ (APME, 2001)
Density			
Oil/diesel	ton/m ³	0.84	rho.olie Energistatistik 2003 (Danish Energy Authority)
Natural gas	ton/thousand Nm ³		
Methane	ton/thousand Nm ³	0.718	rho.methan Steinmüller Taschenbuch, 25 Auflage, 1992
Carbondioxide, CO ₂	ton/thousand Nm ³	1.977	rho.co2 Steinmüller Taschenbuch, 25 Auflage, 1992
Air	ton/thousand Nm ³	1.293	rho.luft Steinmüller Taschenbuch, 25 Auflage, 1992
Nitrogen, N ₂	ton/thousand Nm ³	1.2504	rho.n2 Steinmüller Taschenbuch, 25 Auflage, 1992
Ideal gas v. 20 C, 1 atm.	l/mole	23	vol.idealgas
Specific waste generation per person per year	kg org. waste/pers/yr	100	waste.pers
Substitution of fertiliser			
N substitution	%	60%	subs.andel.N Tønning et al 1997 (Working report from Danish EPA in Danish)
N	MJ/kg	50	subs.N Bundgaard, 1993 (Working report from Danish EPA in Danish)
P	MJ/kg	16	subs.P Bundgaard, 1993 (Working report from Danish EPA in Danish)
K	MJ/kg	8	subs.K Bundgaard, 1993 (Working report from Danish EPA in Danish)

Figure 56: Constant values

19. Energy and Materials LCI's

Worksheet: "Products LCI's"

The worksheet "Products LCI's" includes life cycle inventories for electricity and district heating based on different energy sources. Also LCI for fuel combustion and commercial fertiliser production is included in this worksheet.

Figure 57 and 58 shows LCI's for production of electricity and heat respectively based on a single energy source.

LCI for single energy sources		Energy sources						
Electricity technologies		Coal	Natural gas	Oil	Biomass	Nuclear power	Hydro power	Wind power
Coal	g/MJ	129.0	2.00	0.0	0.1		0.00	1.8
Oil	g/MJ	2.0	0.03	65.0	1.4		0.14	0.2
Natural gas	g/MJ	0.5	58.00	0.0	0.1		0.01	0.3
Orimulsion	g/MJ	0.0	0.00	0.0	0.0			0.0
Biomass	g/MJ	0.0	0.00	0.0	135.0			0.0
Waste	g/MJ	0.0	0.00	0.0	5.0			0.0
Biogas	Nm ³ /MJ	0.0	0.00	0.0	0.0	0.0	0.0	0.0
Energy in/out	MJ	3.5	2.8	2.8	2.1	0.0	0.006	0.1
Emissions								
CO ₂ -bio	g/MJ							
CO ₂ fossil	g/MJ	208	126	194	5		0.440	5.500
CO	g/MJ	0.042	0.004		0.610		0.001	0.006
CH ₄	g/MJ	0.382	0.012		0.001		0.000	0.010
SO ₂	g/MJ	0.078	0.014	0.555	0.200		0.010	0.017
HCl	g/MJ	0.000	0.000		0.060		0.001	0.001
NO _x	g/MJ	0.140	0.375	0.190	0.270		0.000	0.019
NH ₃	g/MJ	0.000	0.000		0.000			0.000
N ₂ O	g/MJ	0.000	0.000		0.000		0.000	0.000
NM VOC	g/MJ	0.007	0.001		0.005		0.003	0.001
NO ₃ -N	g/MJ	0.000	0.000		0.000		0.000	0.000
N-tot	g/MJ	0.004	0.000				0.000	0.000
P-tot	g/MJ	0.000	0.000					0.000

Figure 57: Life cycle inventory for electricity technologies

District heating production technologies		Coal	Natural gas	Oil	Biomass	Nuclear power
Coal	g/MJ	43.0	0.7	0.0	0.0	0.0
Oil	g/MJ	0.7	0.0	21.7	0.5	0.0
Natural gas	g/MJ	0.2	19.3	0.0	0.0	0.0
Orimulsion	g/MJ	0.0	0.0	0.0	0.0	0.0
Biomass	g/MJ	0.0	0.0	0.0	45.0	0.0
Waste	g/MJ	0.0	0.0	0.0	1.7	0.0
Biogas	Nm3/MJ	0.0	0.0	0.0	0.0	0.0
Energy in/out	MJ/MJ	1.2	0.9	0.9	0.7	0.0
Emissions						
CO2-bio	g/MJ					
CO2 fossil	g/MJ	69.3	42.0	64.7	1.7	0.0
CO	g/MJ	0.0	0.0	0.0	0.2	0.0
CH4	g/MJ	0.1	0.0	0.0	0.0	0.0
SO2	g/MJ	0.0	0.0	0.2	0.1	0.0
HCl	g/MJ	0.0	0.0	0.0	0.0	0.0
NOX	g/MJ	0.0	0.1	0.1	0.1	0.0
NH3	g/MJ	0.0	0.0	0.0	0.0	0.0
N2O	g/MJ	0.0	0.0	0.0	0.0	0.0
NM VOC	g/MJ	0.0	0.0	0.0	0.0	0.0
NO3-N	g/MJ	0.0	0.0	0.0	0.0	0.0
N-tot	g/MJ	0.0	0.0	0.0	0.0	0.0
P-tot	g/MJ	0.0	0.0	0.0	0.0	0.0

Figure 58: Life cycle inventories for district heating technologies

Figure 59 and 60 shows the national mixes for production of electricity and district heating respectively. For single energy sources the mix consists of 100% of the given energy source.

Distribution between electricity mix for nordic countries

Electricity	Coal	Natural gas	Oil	Biomass	Nuclear power	Hydro power	Wind power	
Denmark, average	50%	50%	0%	0%	0%	0%	0%	100%
Finland, average								
Norway, average								
Sweden, average								
Coal	100%	0%	0%	0%	0%	0%	0%	100%
Natural gas	0%	100%	0%	0%	0%	0%	0%	100%
Oil	0%	0%	100%	0%	0%	0%	0%	100%
Biomass	0%	0%	0%	100%	0%	0%	0%	100%
Nuclear power	0%	0%	0%	0%	100%	0%	0%	100%
Hydro power	0%	0%	0%	0%	0%	100%	0%	100%
Wind power	0%	0%	0%	0%	0%	0%	100%	100%

Figure 59: National mixes for electricity technologies

Distribution between heat mix for nordic countries

Heat	Coal	Natural gas	Oil	Biomass	Nuclear power	
Denmark, average	50%	50%	0%	0%	0%	100%
Finland, average						0%
Norway, average						0%
Sweden, average						0%
Coal	100%	0%	0%	0%	0%	100%
Natural gas	0%	100%	0%	0%	0%	100%
Oil	0%	0%	100%	0%	0%	100%
Biomass	0%	0%	0%	100%	0%	100%
Nuclear power	0%	0%	0%	0%	100%	100%

Figure 60: National mixes for district heating technologies

The national mixes and the life cycle inventory are calculated on the basis of Figure 57 to Figure 60 and shown in Figure 61 and Figure 62.

LCI for energy technology mixes

		Energy technologies										
Electricity		Denmark, average	Finland, average	Norway, average	Sweden, average	Coal	Natural gas	Oil	Biomass	Nuclear power	Hydro power	Wind power
Coal	g/MJ	65.50	0.00	0.00	0.00	129.00	2.00	0.00	0.05	0.00	0.00	1.80
Oil	g/MJ	1.02	0.00	0.00	0.00	2.00	0.03	65.00	1.40	0.00	0.14	0.22
Natural gas	g/MJ	29.25	0.00	0.00	0.00	0.50	58.00	0.00	0.10	0.00	0.01	0.30
Orimulsion	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	135.00	0.00	0.00	0.00
Waste	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	0.00	0.00	0.00
Biogas	Nm3/MJ											
Energy in/out	MJ/MJ	3.2	0.0	0.0	0.0	3.5	2.8	2.8	2.1	0.0	0.0	0.1
Emissions												
CO2-bio	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO2 fossil	g/MJ	167.00	0.00	0.00	0.00	208.00	126.00	194.00	5.00	0.00	0.44	5.50
CO	g/MJ	0.02	0.00	0.00	0.00	0.04	0.00	0.00	0.61	0.00	0.00	0.01
CH4	g/MJ	0.20	0.00	0.00	0.00	0.38	0.01	0.00	0.00	0.00	0.00	0.01
SO2	g/MJ	0.05	0.00	0.00	0.00	0.08	0.01	0.56	0.20	0.00	0.01	0.02
HCl	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.06	0.00	0.00	0.00
NOX	g/MJ	0.26	0.00	0.00	0.00	0.14	0.38	0.19	0.27	0.00	0.00	0.02
NH3	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N2O	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NMVOC	g/MJ	0.00	0.00	0.00	0.00	0.01	0.00	0.00	0.01	0.00	0.00	0.00
NO3-N	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-tot	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P-tot	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 61: LCI's for electricity mixes

Energy technologies										
Heat		Denmark, average	Finland, average	Norway, average	Sweden, average	Coal	Natural gas	Oil	Biomass	Nuclear power
Coal	g/MJ	21.83	0.00	0.00	0.00	43.00	0.67	0.00	0.02	0.00
Oil	g/MJ	0.34	0.00	0.00	0.00	0.67	0.01	21.67	0.47	0.00
Natural gas	g/MJ	9.75	0.00	0.00	0.00	0.17	19.33	0.00	0.03	0.00
Orimulsion	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Biomass	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	45.00	0.00
Waste	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	1.67	0.00
Biogas	Nm ³ /MJ									
Energy in/out	MJ/MJ	1.1	0.0	0.0	0.0	1.2	0.9	0.9	0.7	0.0
Emissions										
CO ₂ -bio	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
CO ₂ fossil	g/MJ	55.67	0.00	0.00	0.00	69.33	42.00	64.67	1.67	0.00
CO	g/MJ	0.01	0.00	0.00	0.00	0.01	0.00	0.00	0.20	0.00
CH ₄	g/MJ	0.07	0.00	0.00	0.00	0.13	0.00	0.00	0.00	0.00
SO ₂	g/MJ	0.02	0.00	0.00	0.00	0.03	0.00	0.19	0.07	0.00
HCl	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.02	0.00
NO _X	g/MJ	0.09	0.00	0.00	0.00	0.05	0.13	0.06	0.09	0.00
NH ₃	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N ₂ O	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NM _{VOC}	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
NO ₃ -N	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
N-tot	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
P-tot	g/MJ	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00

Figure 62: LCI's for district heating mixes

The chosen energy source or national mix for electricity and district heating made in the input data box 5 defines the LCI's for these. Also LCI's for oil and natural gas combustion is included together with commercial N, P and K fertilisers, see Figure . The energy demand is calculated and marked with blue.

		Power		Heat						
Chosen MIX		Coal	Biomass							
Coal	g/MJ	129.0	0.0							
Oil	g/MJ	2.0	0.5							
Natural gas	g/MJ	0.5	0.0							
Orimulsion	g/MJ	0.0	0.0							
Biomass	g/MJ	0.0	45.0							
Waste	g/MJ	0.0	1.7							
Biogas	Nm3/MJ	0.0	0.0							
Energy in/out	MJ/MJ	3.5	0.7							
Emissions										
CO2-bio	g/MJ	0.0	0.0							
CO2 fossil	g/MJ	208.00	1.67							
CO	g/MJ	0.04	0.20							
CH4	g/MJ	0.38	0.00							
SO2	g/MJ	0.08	0.07							
HCl	g/MJ	0.00	0.02							
NOX	g/MJ	0.14	0.09							
NH3	g/MJ	0.00	0.00							
N2O	g/MJ	0.00	0.00							
NM VOC	g/MJ	0.01	0.00							
NO3-N	g/MJ	0.00	0.00							
N-tot	g/MJ	0.00	0.00							
P-tot	g/MJ	0.00	0.00							

Diesel oil combustion, EURO2*		Natural gas combustion	N-fertiliser	P-fertiliser	K-fertiliser	
per liter	per Nm3	per kg	per kg	per kg		
11.7	1.08E+01	240	138	43.1		g
912	45.6	358	120	22.5		g
50.4	1060	1579	234	163		g
		232	463	57.15		g
1.05E+00		0.0	0.0	0.0		g
		0.0	0.0	0.0		g
41.7	53.1	103.8	32.8	11.5		MJ
Emissions						
0						g
3.0E+03	2.9E+03	6290	1870	663		g
7.3E+00	1.5E+00	4.1	1.1	0.3		g
3.7E+00		1.7	0.6	0.2		g
2.1E+00	6.5E-01	9.8	36.0	0.2		g
3.9E-03	1.0E-02	0.2	0.1	0.1		g
2.6E+01	5.9E+00	24.6	3.2	0.8		g
8.5E-03		8.0	0.0	0.0		g
9.4E-02	4.0E-01	30.2	0.1	0.1		g
7.2E+00		0.2	0.3	0.1		g
0.03						g
0.0186						g
0.0004			45			g

Figure 63: Chosen electricity and district heating technology and LCI for oil and gas combustion and for fertiliser production

20. Definition of Waste and Treatment Technologies

Worksheet: “Names & ID’s”

In worksheet “Names & ID’s” all names for waste compositions, treatment and transportation technologies, energy sources and normalisation references are defined. The ID is used as a constant name in calculations where the technology name can be modified by the user when changing a technology. The sheet is shown in Figure 64.

Waste types and treatment technologies	Technology names	ID	Description
A: Waste composition			
Source separation, Method 1	Copenhagen, paper bags	A.met1	Source separation, Method 1
Source separation, Method 2	Kolding, plastic bags	A.met2	Source separation, Method 2
Source separation, Method 3	Vejle, plastic bags	A.met3	Source separation, Method 3
Source separation, Method 4	Ålborg, plastic bags	A.met4	Source separation, Method 4
Source separation, Method 5	Grindsted, paper bags	A.met5	Source separation, Method 5
Source separation, Method 0	Organic waste, default	A.default	Source separation, Method 0
B: Pre-treatment			
Pre-treatment, Technology 1	Disc screen	B.met1	Pre-treatment, Technology 1
Pre-treatment, Technology 2	Hydraulic screw press	B.met2	Pre-treatment, Technology 2
Pre-treatment, Technology 3	Pre-treatment 3	B.met3	Pre-treatment, Technology 3
Pre-treatment, Technology 4	Pre-treatment 4	B.met4	Pre-treatment, Technology 4
Pre-treatment, Technology 5	No pre-treatment	B.met5	Pre-treatment, Technology 5
Pre-treatment, Technology 0	Default pre-treatment	B.default	Pre-treatment, Technology 0
C: Anaerobic digestion			
	Anaerobic digestion	Treatm.1	
Biogas plant, Technology 1	Grindsted, mesophilic	C.met1	Biogas plant, Technology 1
Biogas plant, Technology 2	Herning, thermophilic	C.met2	Biogas plant, Technology 2
Biogas plant, Technology 3	Vaarst-Fjellerad, thermophilic	C.met3	Biogas plant, Technology 3
Biogas plant, Technology 4	Other biogas 1	C.met4	Biogas plant, Technology 4
Biogas plant, Technology 5	Other biogas 2	C.met5	Biogas plant, Technology 5
Biogas plant, Technology 0	Default biogas plant	C.default	Biogas plant, Technology 0
E: Biogas utilisation			
Biogas energy plant, Technology 1	Grindsted, electricity production	E.met1	Biogas energy plant, Technology 1
Biogas energy plant, Technology 2	Herning, combined heat & power	E.met2	Biogas energy plant, Technology 2
Biogas energy plant, Technology 3	Vaarst-Fjellerad, combined heat & power	E.met3	Biogas energy plant, Technology 3
Biogas energy plant, Technology 4	Upgrade and use in busses	E.met4	Biogas energy plant, Technology 4
Biogas energy plant, Technology 5	Other gas use 1	E.met5	Biogas energy plant, Technology 5
Biogas energy plant, Technology 0	Default energy production	E.default	Biogas energy plant, Technology 0

L: Combined biological treatment		Combined bio-treatment	Treatm.3	
Combined bio-treatment, Technology 1	Aikan	L.met1	Combined bio-treatment, Technology 1	
Combined bio-treatment, Technology 2	Other combined 1	L.met2	Combined bio-treatment, Technology 2	
Combined bio-treatment, Technology 3	Other combined 2	L.met3	Combined bio-treatment, Technology 3	
Combined bio-treatment, Technology 4	Other combined 3	L.met4	Combined bio-treatment, Technology 4	
Combined bio-treatment, Technology 5	Other combined 4	L.met5	Combined bio-treatment, Technology 5	
Combined bio-treatment, Technology 0	Default combined bio-treatment	L.default	Combined bio-treatment, Technology 0	
F: Incinineration		Incineration	Treatm.4	
Incineration plant, Technology 1	CHP	F.met1	Incineration plant, Technology 1	
Incineration plant, Technology 2	Heat plant	F.met2	Incineration plant, Technology 2	
Incineration plant, Technology 0	Default incineration	F.default	Incineration plant, Technology 0	
H: Land use				
Use of fiber fraction, Technology 1	Plant, clay, west DK	H.met1	Use of fiber fraction, Technology 1	
Use of fiber fraction, Technology 2	Dairy, clay, west DK	H.met2	Use of fiber fraction, Technology 2	
Use of fiber fraction, Technology 0	Pig, clay, east DK	H.default	Use of fiber fraction, Technology 0	
S: Collection				
Collection, Method 1	Single family housing	S.met1	Collection, Method 1	
Collection, Method 2	Multi family housing	S.met2	Collection, Method 2	
Collection, Method 3	City areas	S.met3	Collection, Method 3	
Collection, Method 4	Urban areas	S.met4	Collection, Method 4	
Collection, Method 0	Mixed residential areas	S.default	Collection, Method 0	
T: Transport				
Transport, Method 1	Diesel oil, combusted in Euro2	T.met1	Transport, Method 1	
Transport, Method 2	Diesel oil, combusted in Euro3	T.met2	Transport, Method 2	
Transport, Method 3	Methane combustion	T.met3	Transport, Method 3	
Transport, Method 0	Default transport	T.default	Transport, Method 0	

M: Energy sources

Energy source, Method 1	Denmark, average	M.met1	Energy source, Method 1
Energy source, Method 2	Finland, average	M.met2	Energy source, Method 2
Energy source, Method 3	Norway, average	M.met3	Energy source, Method 3
Energy source, Method 4	Sweden, average	M.met4	Energy source, Method 4
Energy source, Method 5	Coal	M.met5	Energy source, Method 5
Energy source, Method 6	Natural gas	M.met6	Energy source, Method 6
Energy source, Method 7	Oil	M.met7	Energy source, Method 7
Energy source, Method 8	Biomass	M.met8	Energy source, Method 8
Energy source, Method 9	Nuclear power	M.met9	Energy source, Method 9
Energy source, Method 10	Hydro power	M.met10	Energy source, Method 10
Energy source, Method 11	Wind power	M.met11	Energy source, Method 11

N: Normalisation references

Normalisation Method 1	Normalisation DK	N.met1	Normalisation Method 1
Normalisation Method 2	Normalisation FIN	N.met2	Normalisation Method 2
Normalisation Method 3	Normalisation ICE	N.met3	Normalisation Method 3
Normalisation Method 4	Normalisation NO	N.met4	Normalisation Method 4
Normalisation Method 5	Normalisation SWE	N.met5	Normalisation Method 5
Normalisation Method 6	Normalisation EU	N.met6	Normalisation Method 6
Normalisation Method 7	Normalisation Global	N.default	Normalisation Method 7

Figure 64: Table of names, ID's and description of technologies in the Biowaste model

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